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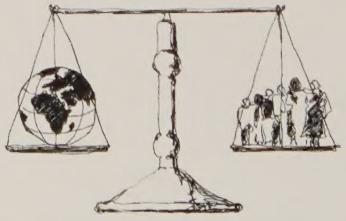

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Effects of organic nitrogen fortifiers on some growth parameters of green amaranths (*Amaranthus caudatus* L.)

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Accepted 29 September 2009; First published online 18 September 2009 **Preliminary Report**

Abstract

Chemical fertilizers for boosting crop production are becoming more expensive and scarce. Green amaranth (*Amaranthus caudatus* L.) is a fast growing and highly nutritious crop, but its common use in the diet of Nigerians is constrained by its high demand for nitrogen fertilizer. Thus, there is a need to find local fertilizer materials that are readily available to peasant farmers. A preliminary field study was conducted to evaluate urine and neem (*Azadirachta indica* L. juss) as alternative sources for mineral fertilizers in fortifying organic fertilizer (OF) made from cow dung and market waste compost, and OF fortified with urea and bone meal [organo-mineral fertilizer (OMF)], for yield and growth of green amaranth. Fifteen treatments, based on the percentages of N supplied, were NPK15-15-15, OMF, OF, urine, neem and ten treatments of 50, 60, 70, 80 or 90% OF supplemented with a total of 50, 40, 30, 20 and 10% urine or neem, respectively, to provide a total application rate of 100 kg N ha^{-1}, with no fertilizer treatment as a control. Planting was done in two successions (main with fertilizer treatments and residual without further application). The fertilizer sources and levels had significant effects on plant height, number of leaves, stem girth, fresh weight and dry weight. The residual effects were also significant for plant height, number of leaves, total fresh and dry weights. Forty percent N urine amendment of the OF produced the highest total fresh amaranth biomass (269.3 g $plot^{-1}$ main effect and 110.8 g $plot^{-1}$ residual effect), which was significantly better than the values of (140 and 35.3 g $plot^{-1}$, respectively) obtained with respect to OMF during main planting and NPK during residual planting. Results of our study reveal that 40% N urine fortification of OF was a viable substitute for synthetic fertilizers in production of amaranth, and that urine and neem cake can be alternatives to mineral fertilizer for crop production.

Key words: urine, neem, amaranth, fertilizer fortification, soil fertility

Introduction

Each year, the finite capacity of tropical soils grow food and fiber has progressively decreased, largely because of the decline in soil fertility[1–4]. Therefore, management of the soil in order to prevent further degradation and declining soil productivity is imperative[5].

Conventionally, farmers use mineral fertilizers that are usually not readily available in most developing countries. Currently, some commercial organic fertilizers (OFs) and organo-mineral fertilizers (OMFs) are being developed. The mineral fertilizer (mostly NKP) is currently at least four times more expensive than the most expensive organic sources. This necessitates the search for local materials that can be readily available (as fertilizers) to peasant farmers; even if they are not as effective as the conventional ones. In this case, OFs readily come to mind. One of the major problems with OF sources is their low nutrient status, a situation that could be corrected by fortification with higher nutrient sources.

Benefits of OFs include the slow-release pattern of N and S, supply of most of the essential cations and micronutrients, contribution to the soil pore system (macroporosity, microporosity, pore space and size distribution and type of soil structure), aggregate stability, soil crusting, water retention, water movement, soil strength, penetration resistance, soil compaction and bearing capacity[6,7]. Application of OFs improves soil physical properties by improving porosity and aggregate stability, thereby reducing formation of a surface crust[6,7]. These benefits often lead to increase productivity of crops. Thus, sustainable production of crops on tropical soils greatly requires input of OF sources.

Among organic materials of high nutrient value that can be used as alternative sources of nutrient amendment are

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Table 1. Total N analysis of OFs used.

Fertilizer material	Total N ($g\,kg^{-1}$)
OMF	44.20
OF	16.80
Neem cake powder	35
Human urine	10

Analytical results indicated OMF having greater total N content than other treatments used, while the lowest was recorded in human urine.

urine, neem cake, palm kernel cake, castor oil seed cake and compost from drumstick (Moringa) tree, *Gliricidia sepium* and sunflower. Human urine is an excellent high nitrogenous liquid fertilizer. Studies indicate that each person's waste fluid can provide enough nitrogen, phosphorus and potassium to grow a year supply of wheat and maize for that person[8]. Neem cake is a good OF because of its high a zadirachtin content with high NPK value[9].

The nutrients in urine are in forms which are readily available to plants. The nitrogen is in the form of urea, which readily degrades to ammonium and nitrate, both of which are available to plants. The phosphorus is mainly in the form of phosphate ions, the potassium in the form of potassium ions and the sulfate in the form of sulfate ions. This means that they are all in forms that are taken up readily by plants. This makes urine a unique biologic fertilizer[10]. In many other parts of the world it is also a tradition to keep the urine and feces apart. The old Japanese practice of night soil recovery from urban areas separated urine and feces, since urine was regarded as a valuable fertilizer[11]. In Yemen, the urine is drained away and evaporated on the outer surface of multi-storey buildings to obtain the feces as a dry fraction without smell for later use as fuel, a system that has been in use for hundreds of years[12].

Of crucial importance also is the acceptance of urine as a fertilizer by the market. At present the EU does not include human urine on the list for approved fertilizers in organic farming, whereas the International Federation of Organic Agriculture Movements (IFOAM) allows urine (and feces) if sanitary requirements are met[13]. In a healthy individual, the urine is sterile in the bladder. The urine can be collected in ordinary *jerry cans* or, if this is more suitable, in large tanks. The fate of the enteric pathogens entering the urine tank is of vital importance for the hygiene risks related to the handling and reuse of the urine. Survival studies of bacteria in urine have been performed at 4 and 20°C. Their persistence was also investigated at different dilutions of the urine and at different pH values. Bacteria were added or originally present in the urine mixture. At different time intervals, the bacteria were enumerated and T90-values (time for 90% inactivation) for the different organisms were then estimated[10].

Green amaranth (*Amaranthus caudatus* L.), a fast growing and highly nutritious crop common in the diet of Nigerians, was used as a test crop in this experiment.

Table 2. Effects of organic nitrogen fortifiers on height (cm) of amaranth.

Treatments	Planting mode	
	Main[1]	Residual[2]
Control	25.43c	14.73ab
NPK	37.66ab	12.79b
OMF	35.29c	16.98ab
OF	23.72c	21.13ab
Urine	30.01abc	13.09ab
90% OF + 10% urine	32.48abc	18.88ab
80% OF + 20% urine	29.96abc	13.11b
70% OF + 30% urine	32.25abc	6.71ab
60% OF + 40% urine	39.55a	21.21ab
50% OF + 50% urine	32.26abc	15.50ab
100% neem cake	29.93abc	22.49a
90% OF + 10% neem cake	30.34abc	18.63ab
80% OF + 20% neem cake	28.29abc	15.46ab
70% OF + 30% neem cake	29.23abc	19.96ab
60% OF + 40% neem cake	28.53bc	21.00ab
50% OF + 50% neem cake	32.70abc	18.85ab

Means followed by the same letters in a column are not significantly different by Duncan's multiple range test at the 5% level.
[1] Harvested at 4 weeks after planting.
[2] Harvested at 5 weeks after planting.

However, one major constraint to growing this crop is the high cost of mostly available fertilizer sources[4].

A. caudatus was used in the present investigation because it is a good indicator plant for N, P and K nutrients[14]. Fortification of compost with 50% *G. sepium* as a N source has been found to encourage better productivity of *A. caudatus*[15]. Plant growth parameters such as height, girth, number of leaves and fresh weight are often consumers' preference, while dry weight seems to more scientific. Thus, the objective of this report was to evaluate growth responses of green amaranths to application of urine, neem cake and their various fortifications of compost from market wastes. This investigation, although preliminary, could lead to further investigations in utilizing urine and neem cake in crop production and sustainable agricultural resources management for food security.

Materials and Methods

The experimental site is situated at the experimental plot of the Department of Agronomy, University of Ibadan, located in the northern limit of the lowland rainforest zone of western Nigeria (latitude 7.43°N and 3.9°E) having an annual rainfall of 1289.2 mm with bimodal distribution. Experimental soil was low in N, P and K. The choice of this soil with marginal plant essential nutrient was to ensure a response to applied treatments. The amaranth seeds and mineral fertilizer (NPK 15:15:15) were obtained from the Department of Agronomy seed store and urine used was collected from Nnamdi Azikwe Hall of the University of

Table 3. Effects of organic nitrogen fortifiers on number of leaves of amaranth.

Treatments	Planting mode	
	Main[1]	Residual[2]*
Control	10.63c	0.88
NPK	13.75bc	10.22
OMF	13.50bc	11.13
OF	11.75bc	11.75
Urine	12.75bc	11.13
90% OF+10% urine	13.38bc	10.75
80% OF+20% urine	13.13bc	10.35
70% OF+30% urine	12.88bc	11.38
60% OF+40% urine	14.63ab	12.00
50% OF+50% urine	12.75bc	1.22
100% neem cake	12.75bc	11.75
90% OF+10% neem cake	12.88a	11.13
80% OF+20% neem cake	13.25bc	11.13
70% OF+30% neem cake	13.50bc	11.13
60% OF+40% neem cake	13.38bc	12.50
50% OF+50% neem cake	13.88bc	11.65

Means followed by the same letters in a column are not significantly different by Duncan Multiple Range Test at the 5% level.
[1] Harvested at 4 weeks after planting.
[2] Harvested at 5 weeks after planting.
* Not significant ($P>0.05$).

Table 4. Effects of organic nitrogen fortifiers on stem girth (cm) of amaranth.

Treatments	Planting mode	
	Main[1]	Residual[2]*
Control	1.38c	1.43
NPK	2.45a	1.19
OMF	1.85abc	1.44
OF	1.61bc	1.56
Urine	1.83abc	1.35
90% OF+10% urine	2.03abc	1.41
80% OF+20% urine	1.91abc	1.14
70% OF+30% urine	2.29ab	1.53
60% OF+40% urine	2.58a	1.56
50% OF+50% urine	1.96abc	1.40
100% neem cake	1.90abc	1.63
90% OF+10% neem cake	2.51a	1.53
80% OF+20% neem cake	1.98abc	1.34
70% OF+30% neem cake	1.94abc	1.48
60% OF+40% neem cake	1.96abc	1.69
50% OF+50% neem cake	1.91abc	1.36

Means followed by the same letters in a column are not significantly different from Duncan's multiple range test at the 5% level.
[1] Harvested at 4 weeks after planting.
[2] Harvested at 5 weeks after planting.
* Not significant ($P>0.05$).

Ibadan and stored for a month before use[10]. Neem cake was made from crushed neem seeds obtained from Cocoa Research Institute of Nigeria (CRIN), Ibadan, Nigeria. The OF and OMF were obtained from Pacesetters' fertilizer plant, Bodija, Ibadan, Oyo State, Nigeria. The OF comprises cow dung and market waste compost in the ratio 1 : 3. The OMF is OF fortified (for N and P) with urea and bone meal, respectively. The investigation was a field trial laid out in a randomized complete block design with four replicates.

The experimental soil was a loamy sand, slightly acidic with pH of 6.5 and the total nitrogen of 1 g kg^{-1} was lower than the critical level of 1.5 g kg^{-1} soil. The P content of the soil was 7 mg kg^{-1} which was also very low. Exchangeable Ca, K and Mg levels (0.2, 0.1 and 0.1, respectively), were also on the low side. Thus, the soil was suitable for the fertilizer trial experiment.

The investigation was carried out in two successions (main with fertilizer treatments and residual without further application) between November 2005 and February 2006. Seedbed preparation was done manually. Each experimental unit (bed) was 0.65 × 0.50 m in size (0.325 m^2) and there were a total of 64 experimental beds, bringing the total land area for the vegetable production to 63 m^2 (18 × 3.5 m) with 0.5 m spacing between beds. The fertilizer treatments were applied a week before planting and watered adequately to aid nutrient mineralization for plant growth. Fertilizers were applied by drilling. The amaranths plants were thinned to a planting density of 1.8 million plants $hectare^{-1}$ 2 weeks after planting. The experiment was carried out during the dry season, so watering to field capacity was done daily (usually in the morning). Weeding was done manually as the situation demanded.

The fertilizers were applied at a rate of 100 kg N ha^{-1}. Treatments used were: control (no fertilizer), NPK 15:15:15, OMF (grade A), OF (grade B), urine, 90% OF+10% urine, 80% OF+20% urine, 70% OF+30% urine, 60% OF+40% urine, 50% OF+50% urine, neem cake, 90% OF+10% neem cake, 80% OF+20% neem cake, 70% OF+30% neem cake, 60% OF+40% neem cake and 50% OF+50% neem cake. Details of N content of the applied OF treatments are shown in Table 1. OMF had the highest concentration of N.

Data were collected on plant height, number of leaves, stem girth, total fresh and dry weights. Soil samples were analyzed for routine physical and chemical analysis. The data on plant responses were subjected to analysis of variance and the means separated using Duncan's multiple range test.

Results and Discussion

The responses of the crops to the applied fertilizers are hereby presented.

Plant height

At the end of main planting (4 weeks after planting), the tallest plants (mean of 39.55 cm) were those treated with 40% urine N amended OF (Table 2), though not significantly ($P>0.05$) different from effects of other treatments

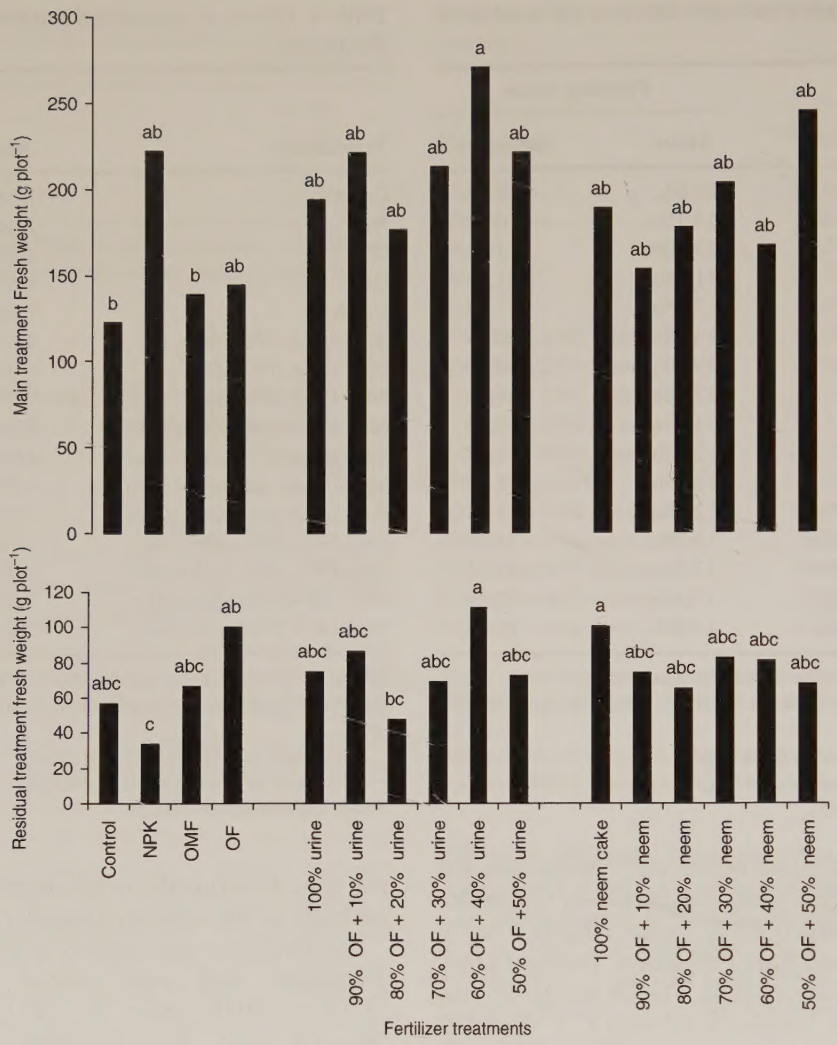

Figure 1. Effects of fertilizer treatments on total fresh weight of *A. caudatus*.

apart from those of control, OMF and OF. The residual effects of the treatments (at 5 weeks after planting), however, took different dimension; the highest crops were those treated with 100% neem cake N (mean of 22.49 cm) with least resulting from those treated with mineral fertilizer NPK, urine and 20% urine fortified OF.

Number of leaves

At the end of main planting (4 weeks after planting), plants (mean of 39.55 cm) treated with 10% neem N amended OF resulted in the highest significantly ($P < 0.05$) different mean number of leaves of 12.88, though not significantly different from effects of 40% urine N amended OF. None of the treatments resulted in a significantly different ($P < 0.05$) number of leaves at 5 weeks after planting (Table 3).

Stem girth

Crops treated with 40% urine N amended OF had the highest stem girth (mean of 2.58 cm) at the end of main planting (4 weeks after planting), though not significantly different from effects of other treatments except those of control and OF. None of the treatments resulted in a significantly different ($P < 0.05$) number of leaves (Table 4).

Fresh plant weight

Crops treated with 40% urine N amended OF had the highest fresh biomass weight (mean of 269 g/plot) at the end of main planting (4 weeks after planting), which was not significantly different from effects of other treatments except those of control and OMF.

At the residual level, the 40% urine N amended OF had the highest fresh biomass weight (mean of 110.8 g plot^{-1}) but this was not significantly different ($P > 0.05$) from the effects of other treatments apart from NPK and 20% urine N amended (Fig. 1).

Dry plant weight

Crops treated with 40% urine N amended OF had the highest dry biomass weight at the end of main planting (4 weeks after planting), which was not significantly

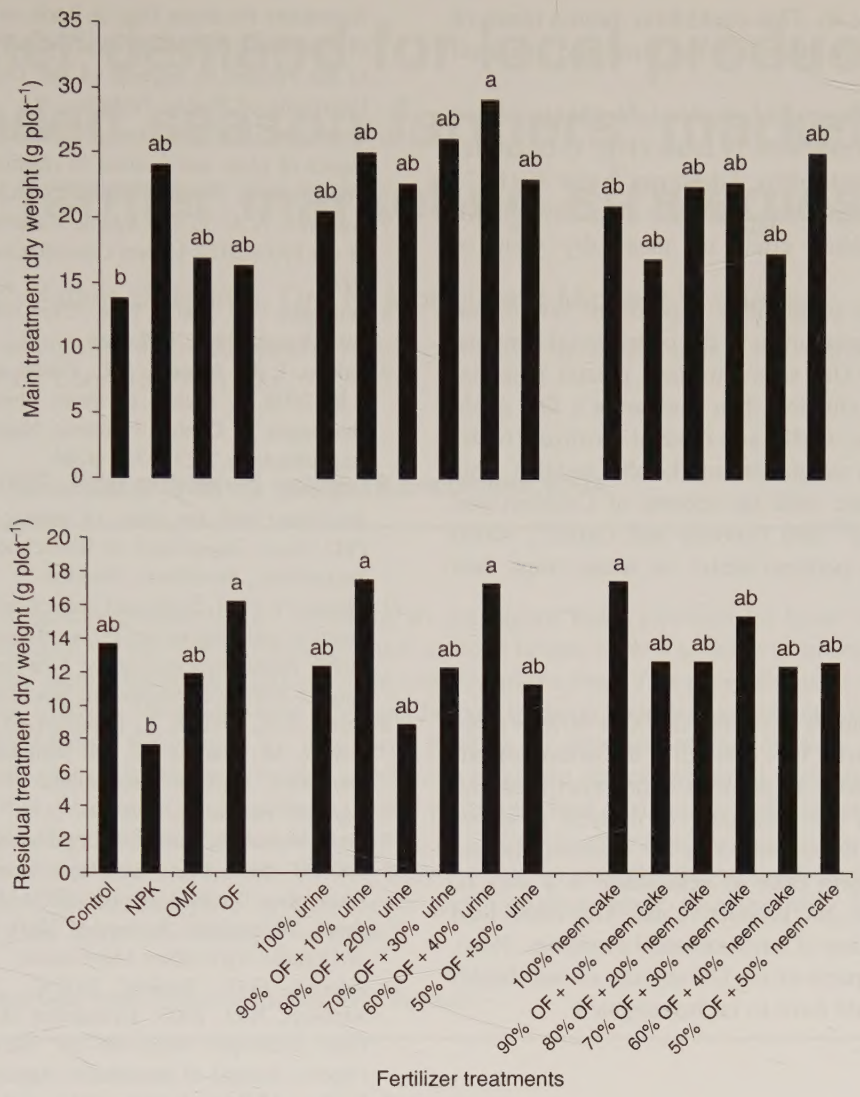
Main treatment dry weight (g plot^{-1})
Residual treatment dry weight (g plot^{-1})
Control
NPK
OMF
OF
100% urine
90% OF + 10% urine
80% OF + 20% urine
70% OF + 30% urine
60% OF + 40% urine
50% OF +50% urine
100% neem cake
90% OF + 10% neem cake
80% OF + 20% neem cake
70% OF + 30% neem cake
60% OF + 40% neem cake
50% OF + 50% neem cake
Fertilizer treatments

Figure 2. Effects of fertilizer treatments on total dry weight of *A. caudatus*.

different from effects of other treatments apart from the control. During the residual effects observation, the 40% urine N amended OF had the highest dry biomass weight but was not significantly different ($P>0.05$) from other treatments apart from NPK (Fig. 2).

Plant growth parameters are of interest to either the consumers or the researchers in different ways. To the consumer, his/her choice of selection of vegetable crops could be determined merely by height, stem girth or how leafy (number of leaves) such leafy vegetables. In this study, the responses of growth parameters of *A. caudatus* to the applied treatments vary. Depending on the interest of the consumer regarding growth parameters, choice of the best performing treatments could be made.

Most of the urine- and neem-treated plants had better growth in terms of mean height than those treated with urea-amended compost. Fertilizer NPK gave the least residual effect on plant height. This means that urine and neem used as fortifiers interacted with the OF to produce better residual effect in relation to plant height. Normally, organic manure does not release the total nutrient value in the life span of most arable crops since mineralization is slow[11]. NPK applied during the main planting might have been leached down the soil by irrigation water and the remaining exhausted by the plants. This could have been the reason why urine and neem resulted in greater value during plant growth.

Plants treated with 10% N neem, 40% N neem and 40% N urine-amended OFs producing the highest number of leaves is an indication that these treatments enhanced leaf production. The residual effects of the treatments on number of leaves was similar to that observed with respect to plant height in that 40% N urine fortification performed much like 40% N neem amendment (Table 3). The reason suggested for the result on plant height is also applicable here. Mineral fertilizer (NPK 15 : 15 : 15) produced the least number of leaves.

In the same vein, 40% N urine and 10% N neem treatments resulted in better stem girth than OMF and

unamended OF (Table 4). This could have been a result of positive complementary effects of the urine and neem on the OF.

The best mean 269 g plot^{-1} fresh yield (34 t ha^{-1}) of amaranths produced from 40% N urine (Fig. 1) is greater than the 20 t ha^{-1} obtained by AdeOluwa[16] and 30 t ha^{-1} reported by Grubben and Van Slotten[17]. This 40% N still had the highest residual effect on mean dry yield of amaranth (Fig. 2).

The results of this preliminary experiment reveal that 40% nitrogen urine amendment of the commercial compost from market wastes (OF) seems to have greater potential to enhance plant production than Pacesetter's OF grade A (fortified with urea) (OMF) and mineral fertilizer (NPK) in terms of total fresh weight (the marketable weight). This result is in consonance with the reports of Grubben and Van Slotten[17], Cooke[18] and Perverly and Gates[19], which stated that sole OFs perform better on some crops than mineral fertilizers.

Conclusion

From the results, it can be recommended that 40% N urine be used to compost with OF. Similarly, the neem amendment showed a tendency to perform better than urea and NPK. Depending on the parameter of interest (whether from the perspective of consumers or the scientist) the use of both urine and neem cake in agriculture is a way of putting organic wastes into productive use. This could lead to sustainable utilization of environmental resources. However, other useful impacts of the OF sources on soil health and crop quality would have to be investigated.

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Consumer demand for local produce at extended season farmers' markets: guiding farmer marketing strategies

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Abstract

Locally grown food is gaining popularity and increasing its prevalence holds potential for broad social, economic and environmental benefits. Season extension technologies such as hoop houses offer a solution to limited growing seasons, a major constraint in many areas, enhancing efforts to supply locally grown food. This paper discusses research conducted at three Michigan farmers' markets, locations where Michigan farmers utilizing hoop houses currently sell their produce. The research measures consumers' willingness to buy local produce at extended season markets using a set of four complementary methods: dot poster surveys, written surveys, focus groups and experimental auctions. Building upon prior research on attributes that create value for local foods (spatial proximity, food quality and relationships between farmers and consumers), our results inform farmers' choice of marketing mix. We find consumers willing to pay a premium for large quantities of locally grown produce, with many placing highest value on products grown in Michigan. We conclude that extended season farmers' markets supplied by hoop house grown produce create an opportunity for farm viability and further development of the market for locally grown food.

Key words: locally grown food, hoop houses, marketing mix, attributes

Introduction

The rising demand and popularity of locally grown food has been a common topic in the popular media[1–3]. The term 'locavore' was deemed the Oxford word of the year for 2007[4]. For many farmers, selling local food may offer a valuable product differentiation strategy, meeting consumer demand for the 'local' attribute[5,6], while increasing their portion of the consumer food dollar.

'Grower-only' farmers' markets are important locations for consumers to source local food[7]. The dramatic rise in the numbers of farmers' markets both nationally[8] and in Michigan[9] further suggests the growth in demand for local food. Farmers' markets are important venues for producers too: farmers can gain price premiums and/or a larger share of the food dollar from these direct sales, as well as entrepreneurial skill and information to meet consumer preferences[10,11]. Several studies also document the social benefits of farmers' markets: building relationships with consumers and information exchange, as well as fun and entertainment[10,12]. Others have reported that extending the market season has positive impact on farmer income[11]. Finally, some discuss spillover benefits from farmers' markets, such as bringing shoppers downtown and providing small business incubation opportunities[13,14]. All of this implies an opportunity for the use of season extension technology as a tool for increasing the direct market exposure of farmers in areas where seasonal markets predominate.

In many respects, Michigan is well placed to meet this demand: it is the second most agriculturally diverse state in the country, producing more than 125 different products[15]. However, the state's climate poses a challenge: most of the state is in agricultural hardiness zones 4 and 5, enjoying at most six frost free months annually[16,17]. These factors severely constrain the state's ability to supply a wide array of foods year round. One promising solution to this seasonality challenge is the use of season extension technologies such as unheated, plastic covered hoop houses (aka, high tunnels), which serve as low cost greenhouses[18].

This paper reports research results measuring consumer demand for locally grown food outside of the customary growing period, focusing on purchases at extended season farmers' markets in three Michigan regions. Here, we begin

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to answer the question: what is the potential market for hoop house grown produce? We asked, for example, if consumers will patronize extended season farmers' markets, how much they would spend and what they would buy. We investigated what product attributes most attract them and how these findings inform farmers' marketing strategies.

Previous Research

The meaning and value of local

Selfa and Qazi[19] defined three broad types of attributes that may define and create value for local foods: geographic location or distance (place), quality of the food—especially freshness (taste) and relationships between participants (face-to-face). The meaning of local food markets varied greatly between farmers and consumers, and among these groups by location within Washington State.

Other studies highlighted similar consumer interest in foods reflecting these 'local' attributes. In a study conducted in Missouri, consumers recognized state boundaries in defining local, but had stronger preference for items grown in a smaller region within the state[20]. Another study, using focus groups of Wisconsin shoppers, found similar ways of defining and valuing local, including location (i.e. driving time, or county or state boundaries), freshness and flavor, and relationships with the farmers[21]. An Ohio study[22] utilized conjoint analysis to measure contributions to consumer utility of three dimensions of local: location (grown in Ohio and 'nearby'), freshness ('harvested yesterday') and farm ownership structure, which roughly parallels the relationship aspect (e.g. 'Fred's Berry Farm' versus 'Berries, Inc.'). Each of the three attribute categories contributed significantly and positively to consumer purchase likelihood.

We theorize that an item meeting all three criteria (location, quality and relationship) would, all things being equal, hold the most value for consumers. The features promoted within the location dimension might include geographic boundaries (grown in a given state, region and county), or miles traveled (distance from farm to market), or supporting the state's or county's taxpayers. The quality dimension may be reflected in freshness ('picked today'), using unique regional products (Michigan tart cherries or Great Lakes whitefish), or attributes not broadly available due to limited demand (grass-fed beef) or difficulty in transport (heirloom vegetables). The relationship dimension can include a range of familiarity, including extended friendships between growers–consumers, conversations at farmers' markets, and labels, brochures and other promotional materials that tell the 'story' of the food and farmers who grew it[23].

Investigators have discussed a range of perceived benefits from local food systems associated with these three dimensions, as well as caveats and constraints. Possible, although controversial, benefits of eating food produced in close proximity included decreased 'food miles' (and concomitant wear on roads, infrastructure and pollution) and improved economic development opportunities[24–28]. Potential perceived quality benefits included improved food safety and nutrition. Food systems based on relationships among participants can bring a host of benefits, including improved land use and community problem-solving capacity[29,30].

Other investigators have provided either outright critique of various stated attributes or tempered them with caveats. For example, investigators have critiqued the use of food miles as an indicator of sustainability[31]. Patterson[32] mentioned a common industry belief that local often implies lower quality, as high quality goods are exported, in addition to questioning the net benefit to farmers of state promotion efforts. Bellows and Hamm[33] cautioned that local does not necessarily co-locate attributes of sustainability and fairness, while Born and Purcell[34] warned of a local 'trap' when assuming local is unambiguously more just and sustainable[34]. Others expressed similar concerns, specifically cautioning against defensive localism[35,36].

Several constraints or barriers to consumption of local foods have emerged as well. Only one consumer in a Wisconsin focus group ($N = 43$) study equated local with season, an obvious constraint in temperate climates, absent the wide use of season extension technology[21]. Brown[20] cited numerous studies that document consumer expectations that local should cost less. Both Brown[20] and Zepeda and Li[7] mentioned the potential search, inconvenience and travel costs of buying local as impeding demand or requiring a lower price.

Effective marketing strategies will be needed to meet this demand. We next examine the literature regarding the four Ps of marketing ('marketing mix')—place, product, price and promotion—regarding these products. Where do consumers buy local foods and how does this impact demand? What products are consumers most interested in buying? What pricing and promotional strategies are likely to be effective?

Locally grown foods can be purchased at many locations. Zepeda and Li[7] provided a narrow definition of local as bought directly from farmers in one's own or a neighboring county, often from farmers' markets, community supported agriculture (CSA) or farm stands. They stated that both farmers' markets and CSA are 'unambiguously local' (p. 2), although in Michigan and elsewhere, many farmers' markets allow the sale of products not grown by the farmer, or even grown out of state: these policies are established by the individual markets (Susan Smalley, Board Advisor, Michigan Farmers Market Association, personal conversation, December 2008). People who shop in health food stores were more likely to buy local food, but the amount or specific food items were not clear[7].

In the Wisconsin study[21], fresh produce, particularly corn, tomatoes, melons and apples, were bought locally by all groups studied, a finding consistent with previous research[37,38]. 'Alternative' shoppers (recruited from a food

cooperative newsletter, Slow Food group and local food festival) gave a broader range of items. However, no mention was made of items consumers do not wish to source locally if available[21].

As with any item, price and quality drive the demand for local foods: if local food is seen as a superior product, consumers will more likely pay a premium. Consumers in Brown's[20] study, who were primarily concerned with freshness and quality, were more likely to buy local, believing it to be fresher and more flavorful. However, only 28% were willing to pay any premium for local, while some (14%) demanded a discount to buy local. In contrast, almost three-fourth of consumers in a Maine study stated a willingness to pay (WTP) more for local[37]. Brown[20] cited numerous studies that document consumer expectations that local *should* cost less. Farmers' price-setting strategies may be informed by consumers' WTP as well set as a markup over production costs. Utilizing a cost-plus pricing strategy increases overall farm income as well as guaranteeing production costs are met[11], suggesting the benefit of this approach.

Howard's[39] research found that most (81%) consumers prefer labels to communicate information about how food was produced, processed or sold (i.e. the impacts on the environment, animal welfare and social justice); slightly fewer (76%) consumers preferred signs or brochures. It is not clear if these findings extend to issues of where or by whom the food was produced, which were found to be less important to consumers' animal product intended purchase decisions[23]. Better understanding of attributes most valued by consumers will inform the content of promotion activities whatever media are used. The remainder of this paper discusses research, which guides the marketing mix for hoop house grown produce sold at Michigan farmers' markets, with particular attention to the three dimensions of local discussed above.

Methods

The methods of this study were approved by Michigan State University's Institutional Review Board (IRB No. X06-340). We utilized four complementary data collection methods: dot poster surveys, written surveys, focus groups and experimental auctions. In aggregate, they provided both depth and breadth of understanding consumers' attitudes and intended behaviors with respect to extended season farmer's market purchases. Copies of surveys, interview guides and auction protocols are available on request from the authors.

Farmers' market data collection occurred between June and August 2007. Initial data utilizing dot surveys and written surveys were collected at three Michigan farmers' markets where farmers participating in a Michigan State University research project on the profitability of hoop houses sell their products [Ann Arbor Farmers' Market (AA), Sweetwater Local Foods Market (SW) in Muskegon and the Sault Sainte Marie Farmers' Market (SSM)]. Customer focus groups were conducted at SW and SSM during this same period. Three experimental auctions were conducted between March and June 2008: one at SW, one at Michigan State University's campus and one at a church in East Lansing.

Dot poster surveys

Dot poster surveys were conducted according to Lev and Stephenson[40]. Dot surveys are an effective method for gathering data from large numbers of respondents in a relatively quick and easy way, resulting in very high response rates. The method consists of simple questions with categorical answers on large posters where dot stickers are placed under appropriate answers by participants. Questions vary according to information desired[40].

Each market had five dot posters, with the following questions (and response categories):

- What is the earliest month you attended this market in 2007? January or February; March or April; May or June.
- If local produce was available what is the earliest month you would be willing to come to this market? January or February; March or April; May or June.
- What is the latest month you attended this market in 2006? July or August; September or October; November or December.
- If local produce was available what is the latest month you would be willing to come to this market? July or August; September or October; November or December.
- How many miles did you travel to attend this market (one way)? 0–5, 6–10; 11–25; more than 25.

In each case, posters were located in a central location at the market and passing customers were asked by researchers and undergraduate research assistants if they were willing to take part in a research concerning this market. While no exact count of refusals was recorded, it appeared that a significant number of customers participated (442 answered at least one question). In cases when the shopper did not attend the market in 2006, they were told not to answer that question.

Written surveys

Following completion of the dot survey, researchers and assistants invited participants to take a written survey. A total of 195 people completed the survey. The survey was intended to solicit more detailed information concerning shopping habits and intended behaviors given certain market scenarios. The survey investigated:

- Market attendance over a specified period (2006 and 2007).
- Intended spending that day (choosing between \$0–10, \$10–25 and more than \$25).

These figures were then combined to calculate the average (mean) expenditure per visit and per year, both for each individual and summed over all shoppers. The average expenditure per person was the weighted average of each

category, where the midpoints of the categories were used for the $0–10 and $10–25 categories (i.e. $5 and $17.5, respectively) and $30 was used for the 'more than $25' category. This mean expenditure was then, multiplied by the number of 2006 visits and the number of respondents to give annual expenditure figures.

Shoppers were also asked to consider the following hypothetical scenario:

> Suppose you are shopping for a bag of fresh salad greens. You have the option of buying (1) produce that was grown outside of the state, or (2) produce that was produced by a local farmer in an unheated greenhouse (hoop house). The two items are the same in size, quality and appearance. Suppose item (1), the salad greens grown outside of the state, cost $2.00 per bag. What is the most you would pay for item (2), local hoop house produce?

Next, the survey asked the consumer to consider the price they named above and asked them on what proportion of produce items they would pay that amount, choosing between these responses: only a few items I buy; many items I buy; most of the items I buy; all of the items I buy. Consumers were given a list of vegetables and asked to check off ones they would particularly like to buy or not buy (with the option to list items not named).

The survey gave a list of attributes pertaining to where and how products are produced, and asked consumers to rate the importance of each in their purchasing decisions on a scale of 1 to 10 (1 being not at all important, 10 being extremely important). The attributes were:

- Grown within 20 miles of this market.
- Grown within 100 miles of this market.
- Grown in Michigan.
- I personally know the farmer who grew it.
- Produce grown with organic methods.

Summary statistics were performed on the written survey data including mean, median and frequency. To determine whether the above values (number of visits, intended spending level, WTP and quantity of local purchases, importance of attributes) differed significantly by location, a Kruskal–Wallis (KW) analysis was used[41], as a Kolmogorov–Smirnov[42] test found none of these variables to be normally distributed.

Focus groups

The third phase of the research included focus groups conducted at two of the markets (SW and SSM). A total of 16 participants took part, eight at each session. Subjects were recruited via market e-mail newsletters circulated by the respective market managers. Focus groups were conducted in a meeting room near the market location. The focus groups included a set of nine questions concerning the shoppers' attitudes, motivations, preferences and behaviors at that market. Participants did not receive topics ahead of time, but instead discussed the questions as they were introduced during each session. Each subject was paid $25 for his/her participation and each focus group lasted about 1 h. The sessions were audio recorded and transcribed.

Focus group data were analyzed by creating a coding system to identify emerging themes. This process involved developing codes to assign meaning to the text of each verbatim transcript. A table was developed to clearly identify the theme, code, definition, rule for application and to provide examples of when to use the codes. Codes were then applied to the data and used for data labeling and data retrieval throughout the analysis[43].

Experimental auctions

Finally, we utilized experimental auctions as a tool to investigate customers' WTP. These have been used effectively for a number of product areas, including irradiated meat and non-GMO corn chips[44,45]. Auctions address a major shortcoming of stated preference methods by imposing a budget constraint on consumer choices.

Between March and June 2008, three experimental auctions were conducted to measure consumer WTP for locally grown salad greens. They took place at (1) SW, recruiting subjects via the market newsletter; (2) Michigan State University, using department list-serves and (3) a church in East Lansing using the church newsletter. A total of 46 people participated.

At each auction, two containers of organic salad greens (approximately one-half pound), one locally grown and one bought the day before in a grocery store, were sold using an English second price auction. The second price auction was used due to its incentive compatible properties[46]. Each item was auctioned three times, and participants were not told the number of rounds, to avoid wealth effects; the binding round was chosen by lot, as was order in each round (local first or second). Participants were given a $25 stipend, which was used to pay for any item won. Upon completion of the auction, participants filled out an exit survey and collected their winnings.

The experimental auction exit survey, in addition to standard demographic information, utilized the same attribute rating questions as the farmers' market written surveys (rate on a scale of 1–10 the importance of grown less than 20 and 100 miles from home, grown in Michigan, knowing the farmer and grown with organic methods). We also asked participants to compare the price they paid at the auction to the proportion of all produce they buy and price they would pay (by percent: 0, 10, 25, 50, 75, 90 and 100). In addition, we asked respondents to recall their bids on the items and to rate on a scale of 1 to 3 (1 if it was of little or no importance, 2 for moderate importance and 3 for great importance) the importance of the following attributes:

- Where the items were grown.
- The type of packaging and label.
- The mix of species/varieties.
- Any factor not listed above.

The respondents were then asked to circle each type of outlet where they acquire significant amounts of

Table 1. First and last month of market attendance, actual and willingness, measured by dot posters (number of shoppers giving each response).

	January or February	March or April	May or later
Earliest actual	95	88	235
Earliest willing	300	114	28
	July or August	**September or October**	**November or December**
Latest actual	17	118	209
Latest willing	1	37	402

produce: supermarket or grocery store; farmers' market, CSA share, health food store/cooperative, farm stand and personal garden.

Results

Dot poster surveys

The dot poster responses indicated that most shoppers would attend the markets both earlier in the Spring and later in the Fall if fresh produce were available. While 23% actually attended markets in January–February, 69% indicted willingness to do so. Most (56%) indicated first attending in May or later. The SSM market did not open until May and those shoppers were therefore unable to attend any earlier. In the remaining two markets, 42% of respondents first attended in May or later. Similarly, 61% last attended in November or December, but 91% would be willing to do so. Full results are presented in Table 1.

Finally, the majority of shoppers (59%) traveled less than five miles to attend the market: the percentages of responses declined as mileage increased. Only 11% traveled more than 25 miles, while 18% and 12% traveled between 6–10 and 10–24 miles, respectively.

Written surveys

Written surveys confirmed that shoppers attended the markets regularly. The mean and medium visits per shopper in 2006 were 18.8 and 12 visits, respectively. Mean and median 2007 visits (up to the date of the survey) were 9.9 and 6. Nine percent attended 50 or more times in 2006, nearly half the maximum total possible visits. When asked how much they intended to spend, 14% responded \$0–10, 47% responded \$10–\$25 and 39% responded more than \$25.

The mean expenditure, as calculated above, was \$20.51. Multiplying by the mean number of 2006 visits (18.8) yielded the average annual expenditure of \$386 per person. Assuming each of the 196 survey respondents spent this amount, the total annual expenditure was \$75,586. Accordingly, if each of the 442 dot poster respondents spent this amount, the total would be \$170,453.

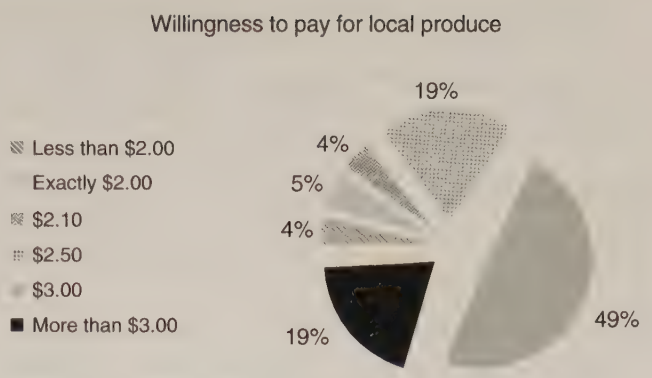

Figure 1. Premiums that consumers ($N = 194$) are willing to pay for locally grown produce. Results of written surveys administered to shoppers at Ann Arbor, Sweetwater and Sault Ste Marie (Michigan) Farmers' Markets, June to August 2007.

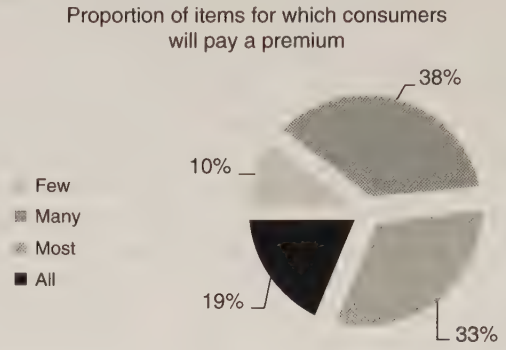

Figure 2. Proportion of produce purchases for which consumers ($N = 165$) are willing to pay a premium. Results of written surveys administered to shoppers at Ann Arbor, Sweetwater and Sault Ste Marie (Michigan) Farmers' Markets, June to August 2007.

The shoppers also indicated WTP a premium for locally grown salad greens: 91% stated WTP a positive premium (Fig. 1). Of those willing to pay a positive premium, more than half (52%) would pay this premium for local on most or all produce they buy (Fig. 2).

When provided a list of (local, hoop house grown) items they would most like to buy, the most common responses were tomatoes (85%), lettuce and spinach (70% each). The vegetable respondents were most likely *not* to buy was radish (26%).

Attributes pertaining to where and how food was grown were important to many of these shoppers, while knowing the farmer was less important. The attribute with the highest mean and median rating was grown in Michigan: the median of 10 indicates more than half of respondents rated this attribute with the highest score. Being produced with organic methods had the next highest mean and median score, while knowing the farmer who grows the food was the least important attribute by this measure (Table 2).

The KW tests revealed that shoppers in different markets responded differently. KW analyses found that four

Table 2. Mean and median rating of selected attributes (10 point scale).

Participant group	Attribute	Grown less than 20 miles away	Grown less than 100 miles away	Grown in Michigan	Knowing the farmer who grew it	Organic methods
Farmers market shoppers	Mean	6.62	6.59	7.88	4.79	7.39
	Median	8	8	10	5	9
Auction participants	Mean	5.11	5.65	6.89	5.22	7.17
	Median	5	7	7	5	8

variables: (i) number of visits in 2006 and (ii) 2007, (iii) intended spending and (iv) the importance of organic methods—differed significantly. The AA market, which had been operating year round for many years in a university town, had the highest group mean for visits both years, while SSM market, in the more rural and less prosperous eastern Upper Peninsula, had the lowest intended spending and rating of organic.

Focus groups

Focus group participants regularly shopped at farmers' markets, meaning that they both attended farmers' markets regularly and purchased a considerable amount of their total weekly food at the markets. Participants indicated that they 'come every week' and that 'most of our produce comes from here.' This behavior was driven by participants' preferences for quality products as well as fondness for the social element of markets.

Several recurring themes emerged as important product attributes or qualities that impacted their decisions to regularly shop at farmers' markets. The four product attributes most important included: (1) product freshness, (2) product taste, (3) locally produced and (4) chemical or pesticide free. Participants stated that they look for items that were 'picked fresh' and indicated the importance of taste compared to items available elsewhere explaining 'it tastes better'. One participant affirmed, 'tomatoes taste like tomatoes and onions taste like onions'. In addition, participants shopped at farmers' markets to support local farmers. For example, one participant described, 'I'd rather buy local because I like to support the local growers'. Lastly, participants identified that they could purchase products grown without chemicals or pesticides at farmers' markets. Each of the three markets had farmers selling certified organic produce or produce grown according to organic practices. If not labeled organic, farmers' market consumers have the opportunity to ask farmers about their growing practices. Combined, these attributes were the most important factors influencing farmers' market purchases at the markets studied.

The social component of farmers' markets emerged as equally important. Participants valued the friendly interactions amongst shoppers and the personal relationships they have with farmers and vendors. Participants described the markets as a 'friendly gathering' and indicated that 'personal relationships are important'. These personal relationships, in addition to the product quality, were important factors influencing consumer loyalty. Shoppers tended to return to vendors and continue purchasing from them once they developed a relationship with them. Participants agreed that 'you kind of get to know the vendors—the ones that you want to be regular with'.

Participants also stressed that they enjoyed the diversity of the products available. A market shopper explained, 'I really like the fact that it's a mix of foods. You know, I can get baked goods and I can get meat and eggs and produce and even soap and lotion'. While the price of these products was discussed, its importance varied across the participants.

Overall, both product attributes and social characteristics influenced focus group participants' decisions to regularly shop at farmers' markets. Shoppers selected products from markets based on perceived attributes of: freshness, taste, locally grown and chemical or pesticide free. Additionally, they were able to develop personal relationships with the producers and meet like-minded individuals from their communities.

Experimental auctions

The average bid, over three rounds, was \$2.96 for the one-half pound of local greens and \$2.26 for the non-local greens, implying a \$0.70 (31%) premium. The average bids for local and non-local were significantly different, as measured by a paired means *t* test. Grown in Michigan and with organic methods again had the highest rating, although the auction participants rated organic highest and overall, had lower mean and median ratings on all but one attribute than did the farmers' market shoppers (Table 2).

On average, respondents would typically be willing to pay the local premium (as revealed by the bid) on 63% (mean response) of produce purchases. The median response was 75%. Eleven percent would pay the bid amount for all items. The factor most influencing the participants' bids was where the items were grown: 65% rated this as greatly important, whereas only 9% rated it as not important.

Packaging and label were the least important attribute: 65% rated it as not important and only 7% rated it as greatly important. Roughly equal numbers rated the mix of greens as not (28%), moderate (33%) and greatly (39%) important. Finally, supermarkets (86%) were the most commonly cited place of fresh produce purchases, followed by farmers' markets (67%), health food stores (41%), personal gardens (28%), farm stands (20%) and CSA shares (6%).

Discussion

For much of the nation, as demand for local food grows, the potential to maximize this market rests on addressing seasonality. We propose passive solar hoop houses as a relatively low cost means of extending the season for produce to meet this demand and contribute to farm viability. Our research at Michigan farmers' markets gives cause for optimism.

Based on the data presented above, it is clear that many shoppers at these farmers' markets are loyal customers for the farmer–vendors: appreciating locally grown food and gaining value from various aspects and combinations of local found in Selfa and Qazi's[19] study. They found particular value in foods produced in Michigan (the 'place' dimension) but greater geographic proximity did not increase value, unlike results from Missouri[20]. Relationships with farmers (the 'face to face' dimension) held the least value for written survey respondents. In contrast, farmer–customer relationships were important for the focus group participants, perhaps reflecting a difference between those who self-selected to participate in each activity.

Based on the frequency of visits to farmers' markets and levels of intended spending, these shoppers are already contributing to farm income. Their stated willingness to attend markets late and early in the season and pay premiums (as measured both by survey, stated choice, and auction, revealed choice, methods) on salad greens, and in many cases on other items, suggests potential for growth in the market for extended season produce. The WTP for local contrasted with prior research[20] suggesting the need for a discount.

The results also inform hoop house farmers' marketing strategies. First, given frequency of visits, customer loyalty and full retail prices and assuming that logistical issues with year-round markets can be addressed, farmers' markets can be an even greater income source for farmers. Tomatoes, the most desired products, can be provided both earlier and later than the field-growing season; lettuce and spinach (the next two most desired products) can be supplied throughout the year. These shoppers expressed willingness to buy a wide range of vegetables: only one vegetable (radish) had more than 13% of survey respondents express particular unwillingness to buy. This suggests farmers' ability to sell a broad array of hoop house vegetables year round.

The results also suggest that many consumers will pay premium prices. Both survey and auction methods found consumer WTP premiums for locally grown salad greens (specifically) and other foods. The average premium expressed by survey respondents was slightly greater than that of auction respondents (a difference that is not statistically different), both in absolute and proportionate terms. It is not clear whether any difference in premium was due to method (stated/revealed choice) or sample. Farmers' market shoppers consistently rated importance of attributes more highly than did the auction subjects. In any case, these data suggest consumers' WTP more for local, evidence that a premium pricing strategy may be effective.

Finally, the most important 'local' promotion message may be 'Grown in Michigan' rather than distance (food miles). Knowing the farmer was overall the least important attribute as rated by the farmers' market shoppers, despite the importance of trust-based relationships expressed by some focus group participants. This result is consistent with Howard's[39] study, which finds that consumers overwhelmingly prefer to get information (including 'local') about food products from labels or brochures rather than through interaction with the seller. This may come as welcome news for farmers, who may feel freer to focus on selling rather than socializing on busy markets days, while still perhaps making the time to chat with core customers. Growing with organic methods was also important to many consumers, which is not surprising; several studies have suggested organic growers add diversity and draw customers to farmers' markets[10,12,47].

The results have policy implications as well. First, given the spillover benefits of farmers' markets, municipalities can assist in the establishment of later season markets by helping to find or construct sheltered locations. Internal market policies limiting the sale of non-local produce or requiring labeling of out of region/out of state produce can help to clarify product origins to consumers.

Conclusions

Season extension technologies such as hoop houses can potentially contribute to farm viability by helping farmers extend the market season, one of the major barriers to meeting local food demand. The research discussed in this paper suggests that farmers' market shoppers in Michigan would attend extended season markets and purchase fresh produce grown in hoop houses.

While the data present a consistent picture, they are limited to the shoppers at these three markets on the specific days the research was conducted, and may not be generalizable to other populations. Furthermore, many of the data are based on consumers' stated intentions and recollections, not on observations in the market place. While the experimental auction method does test WTP under a budget constraint, its subjects are not representative of other populations, nor are their actions observed under repeat purchases.

Finally, further research would help to better guide prospective hoop house farmers' marketing mix and overall contributions to local food systems. Conjoint analysis would measure consumers' comparative value of the three dimensions of local and guide effective promotion. Other important questions include: which products are most likely to be profitable? Even in light of farmers' markets sustained growth, will large numbers of the general public attend extended season markets? What policies and strategies are most likely to deliver ancillary social, economic and environmental benefits of local food systems to farmers,

consumers and communities? We hope our research highlights the potential for season extension and generates further interest in efforts to address constraints to local food consumption.

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Protocol for indicator scoring in the soil management assessment framework (SMAF)

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Abstract

Assessment tools are needed to evaluate agronomic management effects on critical soil functions such as carbon sequestration, nutrient cycling and water partitioning. These tools need to be flexible in terms of selection of soil functions to be assessed and indicators to be measured to ensure that assessments are appropriate for the management goals. The soil management assessment framework (SMAF) is being developed to meet this need. The SMAF uses soil physical, chemical and biological indicator data to assess management effects on soil function using a three-step process for (1) indicator selection, (2) indicator interpretation and (3) integration into an index. While SMAF is functional in its present format, it is intended to be malleable so that user needs can be met. Development of additional indicator interpretation scoring curves is one way that this framework can be expanded. Scoring curve development is a multi-step process of identifying an indicator, determining the nature of the relationship of the indicator to a soil function, programming an algorithm and/or logic statements describing that relationship and validating the resulting scoring curve. This paper describes the steps involved in developing an SMAF scoring curve. Scoring curves for interpreting water-filled pore space (WFPS) and Mehlich extractable potassium (K) were developed using the described protocol. This protocol will assist users of the SMAF in understanding how the existing scoring curves were developed and others interested in developing scoring curves for indicators that are not in the current version.

Key words: soil management assessment framework (SMAF), scoring curves, soil indicators, soil quality, potassium, water-filled pore space, ecosystem function

Introduction

Soils perform essential ecosystem functions related to plant growth, air and water quality and recycling of animal and plant products[1]. Soil management affects how well these functions are performed. While we know a great deal about management effects on soil functions, much of this knowledge is site-specific. Extrapolation of results from one site to another is often difficult due to differences in soils, climate and crops. Expanding our knowledge base often requires many site years of data to confidently determine management effects on soils. As farmers become more dynamic in their management and change soil management practices more frequently to meet economic and societal demands, tools are needed to assess management effects on soil function in a timely manner.

Soil functions are often difficult to measure directly and may require long time periods to exhibit quantifiable changes. In contrast, there are soil properties (indicators) that affect or represent soil function, are easy to measure and are sensitive to management[2]. The soil management assessment framework (SMAF) was developed by Andrews et al.[3] as an additive, non-linear indexing tool for assessing soil function. The SMAF is intended for use by land managers and their advisors in assessing ongoing management practices. The goal of the SMAF is to extend current

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assessment efforts that emphasize erosion rates and soil loss tolerances to include the multiple ecosystem functions performed by soils[3]. Since soil function can be degraded by causes other than erosion (e.g. compaction, oxidation of organic matter, salinization and acidification) it is essential that assessment tools offer flexibility in selection of functions to be assessed and indicators to be measured. The SMAF uses soil physical, chemical and biological indicator data to assess management effects on soil function using a three-step process for (1) indicator selection, (2) interpretation and (3) integration into an index. This assessment tool can be used to compare contrasting management practices on a given soil series or to monitor management effects over time within a field. Beta versions of the SMAF are available on the University of Illinois Soil Quality Web site at http://soilquality.org/tools/smaf_intro.html (verified February 18, 2009) or on CD and in a spreadsheet format by contacting the authors.

Andrews et al.[3] demonstrated use of the SMAF using case studies in Georgia, Iowa, California and the Pacific Northwest. These four case studies ranged in scale from plot studies in Georgia and California, to the watershed scale in Iowa, to monitoring sites within major land resource area 9 in the Pacific Northwest. The Georgia study compared the residual effect of fresh versus composted broiler litter in tall fescue (*Festuca arundinacea*) pasture. The SMAF results showed significant differences between the treatments with the soil P score being lower in the compost treatment. The California study compared conventional, low input and organic vegetable production systems. The SMAF results showed highest scores for the organic system and lowest scores for the conventional system. The study in Iowa compared soil quality in a conventionally tilled watershed to that in a ridge tilled watershed and found that the less intensive tillage resulted in higher SMAF scores. The Pacific Northwest study compared soil quality among a number of land uses. The SMAF scores were highest for forest, range and woodland soils and lowest for soils in CRP, annual cropping, or crop–fallow.

Wienhold et al.[4] used published soil indicator data from two long-term studies in the northern Great Plains to compare grazing and cropping intensity effects on soil quality. Grazing intensity ranged from heavily grazed to ungrazed and cropping intensity ranged from crop–fallow to annual cropping. The SMAF ranked soil quality as lowest in heavily grazed and crop–fallow systems and highest in moderately grazed and annually cropped management systems. Scores among management practices were statistically different and the ranking of the management practices agreed with current knowledge of management effects on soil quality.

The SMAF was recently used to compare contrasting management practices over 3 years at eight locations in the Great Plains[5]. The locations used in this study included Swift Current, SK, Sidney, MT, Fargo and Mandan, ND, Brookings, SD, Lincoln, NE, Akron, CO and Bushland, TX. At each location soil quality was compared between a conventional management system and an alternative management system that included reduced tillage or more intensive cropping. At Fargo, Mandan, Lincoln and Swift Current the SMAF score was greater for the alternative management system than for the traditional management system. This study also documented a positive correlation between yield (a production goal) and SMAF scores at Mandan and Swift Current; a negative correlation between residual nitrate (an environmental goal) and SMAF scores at Lincoln, Bushland, Sidney and Fargo; and a positive correlation between soil organic carbon (an environmental or production goal) and SMAF scores at Fargo, Lincoln, Mandan and Swift Current.

The SMAF is currently being used as a tool within the Conservation Effects Assessment Project (CEAP) to identify the most-limiting soil functions and soil properties or processes being affected by various conservation practices at benchmark watersheds throughout the US. Initial sampling has been completed in five states (GA, IA, NH, OK and TX) and scheduled for three others (IN, MD and MS). Sample analysis and interpretation using the SMAF are in progress.

The Soil and Water Conservation Society recently published results from an expert consultation that identified actions needed for more comprehensive soil assessment, management and planning tools[6]. The SMAF was one of the assessment tools evaluated during this workshop and a specific recommendation was that the number of scoring curves available for interpreting soil indicators be increased. Andrews et al.[3] extended a framework proposed by Karlen and Stott[7] to develop the SMAF. The scientific rational for the scoring curve concept has been described but a protocol for developing additional scoring curves is needed.

The SMAF is designed to allow updating and expansion by users to meet their needs. Improvements to the framework may take the form of validation using data for soils, climates and land uses that have yet to be assessed using the SMAF. The current version of the SMAF contains a limited number of scoring curves and further improvement will take the form of developing scoring curves for additional soil indicators. The objective of this paper is to describe the protocol used to develop SMAF scoring curves. This protocol is then used to develop two new scoring curves for inclusion in the SMAF. These additional scoring curves will give users of the SMAF additional soil indicators for possible inclusion in assessing soil management.

Materials and Methods

Protocol description

The SMAF uses non-linear scoring curves to transform soil indicator values into unitless scores[3,7]. Scoring curves represent algorithms, or logic functions linking multiple algorithms, that relate a soil indicator to a function performed by soils. Scoring curves take the general shapes

Table 1. Soil indicators having scoring curves and soil indicators having potential for scoring curve development.

Developed scoring curves	Potential scoring curves
Organic C concentration	Water-filled pore space (WFPS)
Macroaggregate stability	Aggregate mean weight diameter
Microbial biomass C	Mehlich extractable K
Potentially mineralizable N	Extractable Ca
pH	Extractable Mn
Extractable P	Extractable Zn
Microbial quotient (qCO_2)	Nitrate-N
Bulk density	Ammonium-N
Electrical conductivity	β-glucosidase
Sodium adsorption ratio	Fluorescein diacetate hydrolysis
Available water capacity	Others

of more-is-better, less-is-better and mid-point optima. The general shape is predicted from current scientific knowledge about the relationship between the indicator of interest and the function it represents. Upper and lower limits or optima values represent threshold values for the soil indicator outside of which soil function is impaired. Algorithms are constructed to allow shifts in inflection points, creating changes in expected ranges that account for inherent soil differences and the effect of climate on soil function[3]. Scoring curve development involves a number of steps. These steps are:

Identify a soil indicator. The first step in scoring curve development is to identify a soil indicator for which a scoring curve has not been developed, that responds to soil management practices, and affects a soil function related to one or more management goals (e.g. productivity, waste recycling and environmental protection). The current version of the SMAF has scoring curves for 11 soil properties but more than 60 other properties have been identified as having potential as assessment indicators. A partial list of potential assessment indicators is provided in Table 1.

Identify available data sets. Data for constructing a scoring curve can be original data collected specifically for determining the relationship between a soil indicator and a soil function or existing data sets from previous studies. Data sets need to include soil indicator values and a measure of soil function for a range of environmental conditions.

Determine and mathematically define the relationship between the soil indicator and the soil function. This is done by graphing the relationship between a soil indicator and a soil function and determining the general shape of the relationship (e.g. more-is-better, less-is-better, local optima or other, depending on environmental condition). Curve fitting software is then used to develop an algorithm that describes the relationship.

Identify factors that influence the relationship between the soil indicator and soil function. While it is usually assumed that the general shape of the relationship between a soil indicator and a soil function holds across systems, the range for each indicator will frequently vary among systems. The variation from system-to-system results from differences in site-specific factors such as climate or inherent soil properties[3].

Program the curve. An algorithm that describes the relationship between the soil indicator and soil function is entered into a spreadsheet. In addition, a table of parameter changes for factors that cause needed shifts in inflection points or expected ranges for the indicator is created.

Validate the curve. Scoring curve algorithms are used to generate scores using data not used to estimate algorithm parameter values. A number of validation methods, including professional opinion regarding reasonable outcomes, comparison with measured environmental goals (e.g. yield or soil loss), or comparison to other published data sets and their author's conclusions can be used to validate the new scoring curve. Further validation is accomplished as other users implement the SMAF, use the scoring curves and report their results.

Indicator selection and data sets

Two soil indicators were identified as candidates for scoring curve development. These two indicators are not included in the current version of SMAF, are known to respond to management and affect soil functions related to management goals. A physical attribute, water-filled pore space (WFPS) is calculated using an assumed soil particle density (ρ_p) of 2.65 g cm^{-3} and the relatively easily measured soil properties of bulk density (ρ_b) and gravimetric water content (Θ_g). The calculation for WFPS is

$$WFPS = (\Theta_v/TP),$$

where Θ_v is the percent volumetric water content and is equal to ($\%\Theta_g$) (ρ_b) and TP is the total soil porosity and is equal to ($1-\rho_b/\rho_p$). Mehlich extractable K (a chemical soil attribute) is a measure of the availability of an essential plant nutrient. Extractable K relates to the production function of soils. If extractable K decreases, there is an increased probability that yields will be reduced and an increased probability that the crop will respond to fertilizer K.

Data used to develop scoring curves for WFPS were taken from Doran et al.[8] which utilized 18 benchmark soils representing nine soil orders. A production function-scoring curve was developed using data that related WFPS to respiration and nitrification. An environmental function-scoring curve was developed using data relating WFPS to denitrification. A scoring curve for Mehlich extractable K was developed using test interpretation information published by Iowa State University (http://www.extension.iastate.edu/Publications/PM1688.pdf; verified February 18, 2009), University of Nebraska (http://www.ianrpubs.unl.edu/epublic/pages/publicationD.jsp?publicationId=142; verified February 18, 2009), University of Missouri (http://extension.missouri.edu/explore/agguides/soils/g09185.htm; verified April 10, 2009) and the International Fertilizer

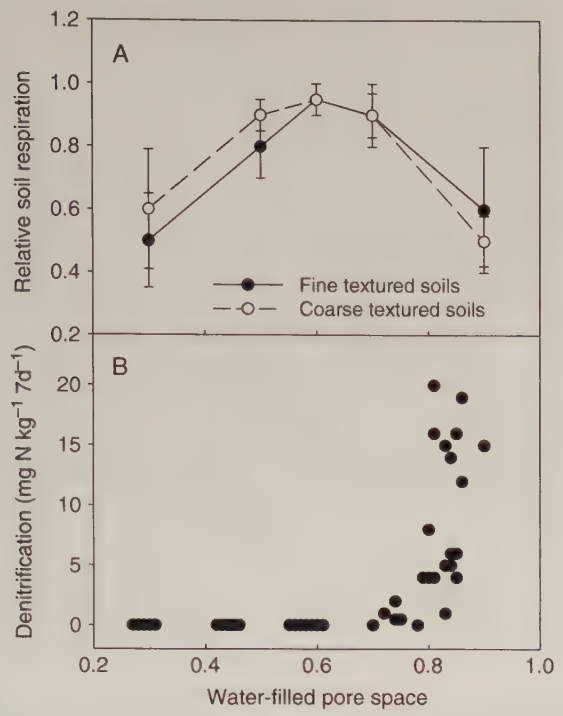

Figure 1. Plot of relative soil respiration versus water-filled pore space (A) and denitrification rate versus water-filled pore space (B) for 18 benchmark soils. Interpolated from Doran et al.[8].

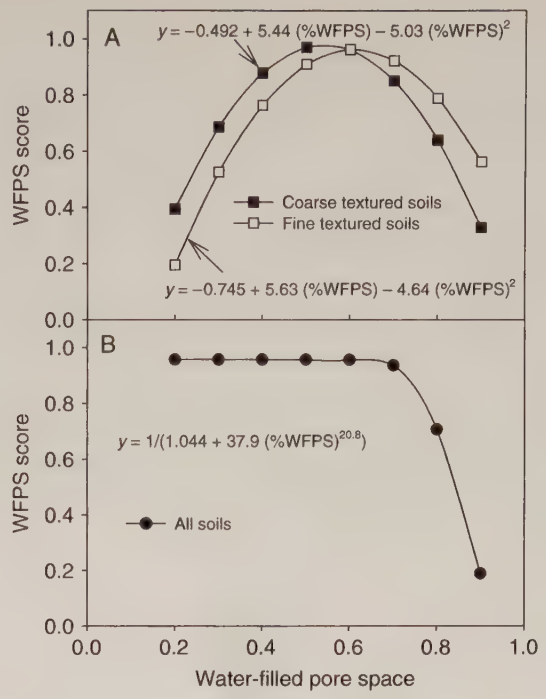

Figure 2. Percentage water-filled pore space scoring curves for two management goals: (A) productivity management using soil texture as a controlling factor and (B) environmental management. Higher score indicates greater performance of ecosystem function. Here, the functions related to the management goal are: water availability for plant production and biotic habitat to support favorable microbial populations and avoidance of anaerobic conditions conducive to denitrifiers.

Industry Association[9]. This interpretation information related extractable K to the probability that crop yields would decrease and that the crop would exhibit a response to K fertilizer.

Curve fitting software [e.g. CurveExpert (Trade or manufacturer's names mentioned do not constitute endorsement, recommendation, or exclusion by USDA), v. 1.3 shareware available online at http://www.ebicom.net/~dhyams/cmain.htm; verified February 18, 2009] was used to develop algorithms describing the relationship between the selected indicators and corresponding soil functions. CurveExpert compares the fit of the data to a library of available models, selects the model having the lowest root mean square error and provides coefficient estimates for the model exhibiting the best fit.

Validation

The production scoring curve for WFPS was validated using growing season soil respiration and WFPS data published by Ding et al.[10]. The environmental scoring curve for WFPS was validated using field measured denitrification data presented in Doran et al.[8]. The scoring curve for extractable K was validated using data describing the yield response of corn to starter fertilizer over 100 site years in Wisconsin[11]. Curves were considered validated if the SMAF score ranking of the management practices was the same as the statistical ranking using soil indicator data in the original studies.

Results and Discussion

WFPS affects root respiration and soil microbially mediated processes and is related to both the crop production and environmental functions of soils. For a production function, very low WFPS values suppress plant growth and microbial activity due to lack of available water. At optimal WFPS values, root growth and microbial processes such as nitrification (N available for plant growth) are greatest. As WFPS values become greater, root growth of most plants is suppressed. Doran et al.[8] presented soil respiration data as relative values with the greatest respiration rate having a value of 1 and lower respiration rates having lower relative values. The SMAF uses a similar approach assigning a value of 1 to the indicator value where the soil function is optimal. When relative respiration data are graphed a mid-point optima curve is indicated (Fig. 1A). Doran et al.[8] presented quadratic functions that related relative soil respiration to WFPS (Fig. 2A). They also described a shift in the relationship between WFPS and soil respiration and nitrification related to soil texture. These equations represent algorithms that describe the relationship between soil respiration and WFPS and identify factors that influence these relationships. These equations can therefore be used directly as scoring curves in the SMAF. The quadratic

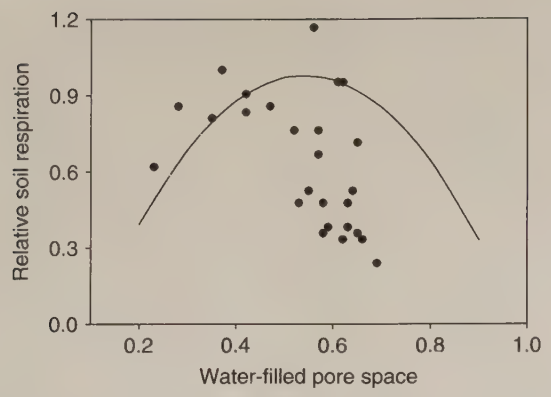

Figure 3. Relative soil respiration as a function of percentage water-filled pore space in a sandy loam Inceptisol (adapted from Ding et al.[10]). The curve represents the SMAF scoring curve for the production goal presented in Fig. 2A.

equation for the WFPS scoring curve is

$$\text{WFPS score} = a + b(\text{WFPS}) + c(\text{WFPS})^2,$$

where coefficient values for coarse textured soils (e.g. sandy, sandy loam and sandy clay loam) are $a = -0.492$, $b = 5.44$ and $c = -5.03$ and for fine textured soils (e.g. silt, silt loam, clay loam and clay) are $a = -0.745$, $b = 5.63$ and $c = -4.64$. For the crop production function, low WFPS levels affect biological activity by limiting water availability and respiration and nitrification rates are reduced. As WFPS increases, respiration and nitrification increases to a mid-point optimum. Further increases in WFPS limit aerobic biological activity by reducing oxygen availability and respiration and nitrification rates decline (Fig. 2A).

Doran et al.[8] presented denitrification rates versus WFPS (Fig. 1B). Denitrification emits N as NO_x, which are greenhouse gases and this process has negative environmental effects. The relationship between denitrification and WFPS suggests a less-is-better scoring curve. The environmental WFPS scoring curve was best fit to a Harris model function:

$$\text{WFPS score} = 1/(1.04 + 37.9(\text{WFPS})^{20.8}).$$

At low WFPS, little denitrification occurs and the effect of this process on the environmental soil function is low resulting in an SMAF score of 1 until a threshold value is reached after which denitrification increases rapidly and the SMAF score decreases (Fig. 2B).

The production scoring curve for WFPS was validated using growing season soil respiration and WFPS data published by Ding et al.[10]. Plotting soil respiration rate against WFPS results in a curve having a midpoint optima shape similar to that of the scoring curve developed above (Fig. 3). Most of the respiration data reported by Ding et al.[10] corresponds to WFPS values between 0.2 and 0.6, which is on the ascending part of the productivity scoring curve (scores of 0.4–1.0). When WFPS values approach 0.6, scores for the production function declined and reported soil respiration rates become more variable and

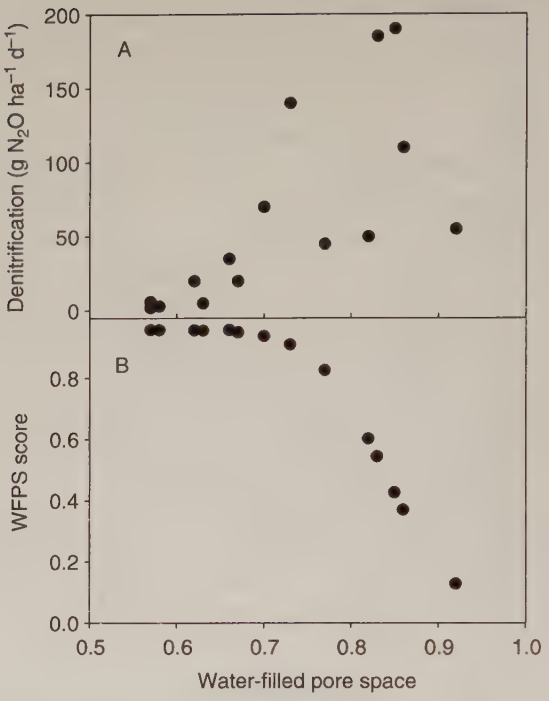

Figure 4. (A) Denitrification as a function of water-filled pore space for a Clarion soil. Interpolated from Doran et al.[8] and (B) corresponding SMAF scores calculated using the environmental goal scoring curve presented in Fig. 2B.

decline. These results are what we would expect based on our knowledge of soil water content effects on aeration and soil microbial activity.

The environmental scoring curve for WFPS was validated using field denitrification data presented by Doran et al.[8] (Fig. 4A). As WFPS values become greater, denitrification activity increases and SMAF scores decrease (Fig. 4B). The scoring curve developed using laboratory measurements produces decreasing scores when WFPS becomes great enough for denitrification activity to begin in field soils.

The potential advantage of using WFPS in place of soil respiration or denitrification measurements relates to the difference in measuring these variables. Measuring soil respiration and denitrification requires chambers, gas sampling equipment, and a gas chromatograph, while WFPS requires a soil probe to collect a sample of known volume, an oven to dry the sample and a balance to weigh the soil sample before and after drying. Time and expense are much lower to determine WFPS. However, when the simple measure is combined with the use of the SMAF scoring curve, the information obtained is very similar to that obtained with the more involved respiration and denitrification methods and WFPS can serve as a surrogate for soil respiration.

The data for developing a SMAF scoring curve for Mehlich extractable K ($mg\,kg^{-1}$) relates relative crop yield to extractable K values (Fig. 5). The data suggest that a more-is-better scoring curve is appropriate with crop yields

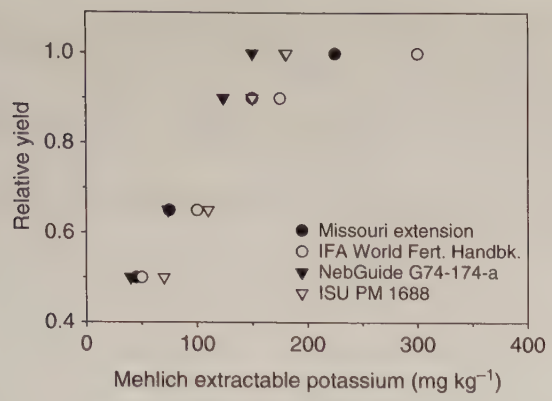

Figure 5. Relative crop yield versus Mehlich soil test K relationships used for fertilizer recommendations. Iowa State University (http://www.extension.iastate.edu/Publications/PM1688.pdf; verified February 18, 2009), University of Nebraska (http://www.ianrpubs.unl.edu/epublic/pages/publicationD.jsp?publicationId=142; verified February 18, 2009), University of Missouri (http://extension.missouri.edu/explore/agguides/soils/g09185.htm; verified April 10, 2009) and the International Fertilizer Industry Association[9].

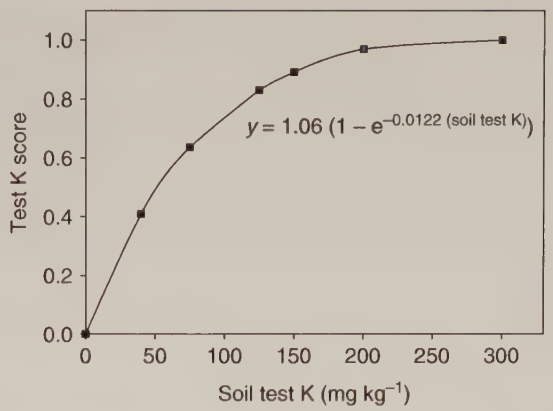

Figure 6. Mehlich extractable K scoring curve. Higher score indicates greater performance of ecosystem function. In this case, higher nutrient availability for plant production.

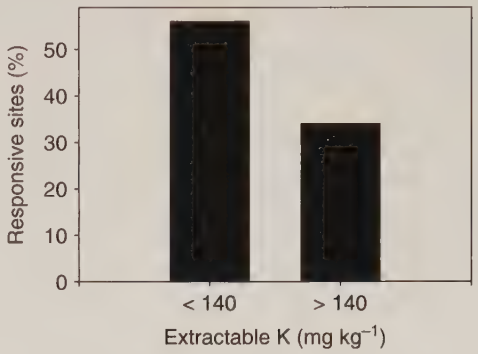

Figure 7. Percentage of sites responsive to potassium fertilization as a function of soil test K in Wisconsin[11].

being limited at low extractable K levels and yields increasing as extractable K increases to a point where extractable K is adequate for crop production. The data relating crop yield to Mehlich extractable K were best fit to an exponential function (Fig. 6). The exponential equation for the extractable K scoring curve is

$$\text{Extractable K score} = 1.06 * (1 - \exp(-0.0122 * \text{Mehlich extractable K})).$$

At low extractable K levels, the probability of reduced yields and a crop response to K fertilizer increases. As extractable K levels increase, the probability of reduced yields and a crop response to K fertilizer decreases[12]. A more-is-better curve is appropriate since there are no major environmental concerns associated with high extractable K values to indicate a need for lower scores for environmental risk at high soil test K values.

The scoring curve for extractable K was validated using data describing the yield response of corn to starter fertilizer over 100 site years in Wisconsin[11]. These authors presented data as the percentage of sites that responded to starter K when Mehlich extractable K levels were $<140\,\text{mg kg}^{-1}$ and the percentage of sites that responded to starter K when Mehlich extractable K levels were $>140\,\text{mg kg}^{-1}$ (Fig. 7). Corn growing in soils with extractable K levels $<140\,\text{mg kg}^{-1}$ produced an SMAF extractable K index value <0.86 and corn growing in soils with extractable K levels $>140\,\text{mg kg}^{-1}$ produced an SMAF score >0.86 (Fig. 7). In these soils, as extractable K levels increased, fewer crop responses to starter K were observed. The Mehlich extractable K SMAF scoring curve can be included with scoring curves for available P and soil nitrate to assess the nutrient availability status of soils for crop production assessments.

The equations discussed above have been programmed into the spreadsheet version of the SMAF. For the WFPS production curve shifts due to factors affecting the indicator–soil function relationship, logic functions such as 'IF', 'THEN' and 'ELSE' were used to select the coefficients appropriate for the soil being assessed. All versions, web, CD and spreadsheet, operate in a similar manner. The web and CD versions use object-oriented Java code linked to a database, while the spreadsheet version uses embedded functions and look-up tables. The spreadsheet version is ideal for adding curves or otherwise manipulating the existing framework. The web and CD versions are better for users simply wanting to use the existing tool 'as is'. These curves will be added to the web and CD versions of the SMAF in the future.

Conclusions

The two scoring curves developed in this paper increase the number of indicators available for users of the SMAF and serve as examples of the steps necessary to develop scoring curves for additional indicators. All scoring curves in the SMAF, including those presented above, can be further refined and validated using appropriate soil

management data bases. The main challenge in validating scoring curves is collecting or identifying data sets that have measures of both the soil indicator of interest and a soil function. Soil indicator data are usually easier to collect than are soil function data, due to the difficulty in measuring functions directly. This difficulty in collecting soil function data results in a research need (e.g. data sets that can be used to validate scoring curves) and identifies the value of assessment tools such as the SMAF. Once a scoring curve is validated, an easy-to-measure indicator can be used with the curve as an interpretive tool to assess management effects on difficult or expensive to measure soil functions. These curves, whether used as part of an overall index of soil function in the SMAF or as interpretations of individual soil functions, can facilitate conservation by land managers through adaptive management, and by policy makers through improved resource and allocation of effort.

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Purchasing foods produced on organic, small and local farms: A mixed method analysis of New England consumers

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Abstract

Research focused on consumer behavior and attitudes toward organic, small-scale and locally produced foods can help organic producers understand consumer values, and in turn develop production and marketing approaches that match these values. This research on New England area food shoppers included focus groups, individual interviews, and a mail survey, all of which helped us to identify relationships between organic food buying and consumers' views of the food system. Comments made in focus groups and individual interviews revealed a frequent blending of the concepts of local, small-scale and organic, and their associated benefits. Subsequent mail surveys identified similar tendencies, although respondents made some distinctions among the reasons why they bought food from the three farm categories. When there were differences, respondents tended to attribute greater importance to reasons to buy from local farms, as compared to organic or small farms. The six questions for which the differences across farm categories had the lowest *P*-values were related to the environment, rural economy, rural landscape, farmers, product freshness and product taste. However, freshness, taste, nutritional quality and safety were some of the most compelling reasons that were attributed to all three farm categories. The challenge for the small, local and organic producer will be to continue to hold the consumer's attention as the general perception of organic farming shifts to a more industrialized model.

Key words: organic food, consumers, local, industrialization, small farms

Introduction

Over the past three decades, the organic farming movement has grown tremendously, reaching a point in the 1990s when it became one of the fastest growing segments of US agriculture[1]. Growth in the global organic food market has naturally paralleled that in organic agriculture, having reached an estimated value of sales at $40 billion in 2006, with fresh produce comprising about one-third of the total[2]. Because success of organic farming will ultimately be based on acceptability of the concept and buying behaviors of consumers, it is essential to focus research on consumer behavior and attitudes toward organic foods.

In popular discussions of trends in the food market, the growth in organic foods is often linked with two related but distinct developments. One is the growing interest in buying locally produced foods. In one nationwide survey, 30% of consumers indicated that they preferred to buy fresh produce from farmers' markets or directly from producers over buying from supermarkets or other markets that do not directly link the consumer and producer[3]. In a statewide survey of Maryland food producers, 74% of the certified organic and 'organic interested' respondents indicated that they wanted to sell locally[4]. In a similar survey targeting Maryland consumers, 79% of respondents indicated that they sought local foods, and 56% said they had purchased certified organic food in the past 6 months[4].

The second development is that organic is favored by some people, not just as a way to avoid chemical residues in their food, but also as part of a more general rejection

†Retired.
‡Deceased.

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of the industrialization of US agriculture at the expense of small-scale and family farming[5]. However, exactly the opposite tendency also has emerged, with organic seen as becoming increasingly like mainstream industrialized agriculture, a trend that some people believe runs counter to the organic philosophy[6].

In a report on US public opinion regarding food, health and farms, Bostrom synthesized existing research that incorporated an assessment of the value that Americans place on organic, local and small-scale farming[7]. She concluded that Americans generally value farms and a strong US agricultural system, but especially favor small family farms over large industrial farms. Locally grown food has become a public priority, and organic products are viewed very positively, but loyal use is rare, with cost being the primary downside. Despite the contradictions between these values and the predominant direction of US agriculture, she concluded that there is little groundswell of public dissatisfaction regarding the current food system.

Other research has compared and contrasted consumers' views about locally produced versus organically produced food. A focus-group study in Wisconsin found that the 'alternative' (organic) shoppers were more likely to seek and use 'local' labels on food than were conventional shoppers, although shoppers in all focus groups had positive attitudes about local food[8]. A telephone survey of 500 households in the Midwest (Nebraska, Iowa, Missouri and Wisconsin) found that more households thought a local label on food was either extremely or very important (48%) compared to those who thought an organic label was extremely or very important (25%). In this survey, top reasons given for buying local were freshness, taste and supporting local farmers, whereas top reasons for buying organic were no chemicals/pesticides, healthy/nutritious and taste[9]. A Missouri mail survey found that environmentalists were willing to pay a higher price for local food and for organic food than were non-environmentalists, although the majority of all respondents stated they cared about where a product was grown[10]. Product quality and freshness were identified as the primary motivators for these respondents[10].

The three areas considered in this paper—organic food, locally grown food and small-scale agriculture—are very different conceptually. Organic farms are not necessarily small, nor do they only sell to nearby consumers. Nevertheless, some people favor all three of these approaches as an attractive alternative to the dominant agricultural system. The basic question is whether consumers who do so critically distinguish among them, or indiscriminately favor all three of them as part of a generalized desire for a better way to produce our food.

The research was conducted in New England. The region's farms tend to be smaller than the national average, and emphasize vegetable, fruit and dairy production, with little production of grains or meat animals. In 2002, there were 28,254 farms in New England, and the average farm size was 141 acres[11]. Just fewer than 8000 of these farms had cattle and calves, 1236 farms had hogs and pigs, and 533 farms sold broilers and other meat-type chickens[11]. Corn for grain was being produced on just 228 farms, and wheat for grain on just 37 farms[11]. In contrast, vegetables were harvested for sale from 2999 farms, and 1635 farms had land in orchards[11].

Considering organic and conventional agriculture in the two states where mail surveys were conducted for this research, we find some similarities and some differences relative to the national level data (see Table 1)[12]. Organic farms in Vermont are much closer in size to non-organic farms in Vermont, compared to Massachusetts organic and non-organic farms or the national average for organic and non-organic farms[12]. Vermont also has a much higher percentage of total farms that are defined as organic (8%) compared to Massachusetts or the nation overall[12]. Although the average size of a Vermont organic farm is close to the average size of an organic farm in the nation, the average Massachusetts organic farm is much smaller[12].

We initially used qualitative methods, including focus groups and individual interviews. Qualitative methods such as these have been used in the past to collect formative data regarding underlying reasons for consumers' organic food purchasing behavior[13–15]. Results of our qualitative research then led us to a specific exploration, using a mail survey, of a number of potentially plausible hypotheses, including the hypothesis that 'the reasons shoppers give for buying organic foods does not differ from the reasons shoppers give for buying foods produced locally, or from the reasons shoppers give for buying foods produced on small farms'. The formative data that led to this hypothesis, as well as the relevant results of the mail survey, will be provided here.

Methods

The qualitative component incorporated five focus groups, followed by 27 individual interviews, all of which were conducted with primary food shoppers in diverse New England households. A purposive, convenience sampling strategy was used to identify participants for both the focus groups and individual interviews, with the primary consideration placed on food shopping habits related to organic foods. Focus group participants were recruited in Vermont and Massachusetts through food shopping sites, including food co-ops, a supermarket, a farmers' market, and through referrals. Two focus groups consisted of 'organic food buyers' (defined by their verbal indication upon recruitment that they bought organic foods with some regularity), two focus groups consisted of shoppers who did not buy organic food (defined by their verbal indication upon recruitment that they never, rarely, or very occasionally bought organic foods), and one focus group contained some of each. Participants for individual interviews were recruited in Vermont, Massachusetts, Connecticut, New Hampshire, and Maine through referrals from friends and colleagues.

Table 1. Number and size of organic farms.

	Number of organic farms	Organic farms as % of total farms	Organic farm size in acres (mean)	Non-organic farm size in acres (mean)	Organic acreage as % of total acreage
Vermont	554	8	109	182	5
Massachusetts	295	4	18	69	1
Nation	18,211	0.8	124	421	0.2

The same interviewer—(L. Berlin), a white, middle-aged, female—conducted all focus groups and individual interviews from February to October 2002. An interview guide, used in each focus group and individual interview, was designed to direct the conversation, while providing flexibility for the investigator to probe further in areas of greatest interest. Each focus group took approximately 2 h, and individual interviews ranged from 1 to 2 h. The guide started with open-ended questions about preferred shopping places, perceptions of the term 'organic', and scenarios that reflected the food shopping experience. It then addressed specific categories of interest, including food safety, the environment, animal welfare, farm worker safety, trust of food system members and industrialization of the food system. The guide used for focus groups was modified before it was used in individual interviews. In addition to the focus group questions, participants in individual interviews were asked about personal dietary changes; their level of interest in food; what they perceived to be advantages and disadvantages of organic foods; their familiarity with irradiation, sewage sludge, genetic engineering and bacterial or fungal contamination; and a few questions that stemmed from two theoretical models, the Health Belief Model[16] and an extension of Schwartz's Norm Activation Model[17].

Almost all interviews were tape recorded (the recorder failed during two of the individual interviews), and the interviewer took written notes as well. Following interviews, all tapes were transcribed and returned to the investigator, who reviewed them for accuracy. Transcripts were then imported into a qualitative data analysis program[18] and coded. For data analysis, comments and discussion topics were examined by the interviewer to discover themes that emerged. These themes formed the basis for conceptions consumers had regarding organic, small and local farms. Additionally, matrices were formed to look for patterns in responses across respondents. Although the interview guide incorporated questions about how the respondent conceptualized the 'ideal food system', the interviewer did not have an initial set of questions explicitly designed to elicit views of local and small-scale farming. However, follow-up questions were asked if the respondent raised these topics. In conducting the analysis, the primary interest was in identifying relationships between organic food buying behavior and other responses. In quoting respondents, there will be an indication of whether the person was from an organic focus group (OFG), a non-organic focus group (NOFG), or a mixed focus group of organic and non-organic buyers (MFG), and in the case of individual interviews (II), the gender and age of the respondent will be included.

The quantitative component involved a mail survey sent to a random sample of 1100 adult residents in three New England communities. Specifically, mail survey recipients lived in Hardwick or Enosburg, Vermont, or Medford, Massachusetts. Hardwick and Enosburg are both rural communities that were selected because of their similar demographic profiles but contrasting shopping opportunities: one has a food cooperative that features organic foods year-round, and the other does not. Medford was chosen to reflect an urban community with diverse types of food marketplaces. As with the qualitative approach, the mail survey targeted the primary food shopper in the household by asking the original recipient either to complete the survey or to pass it along to somebody else in the household who met this qualification. The sample was randomly selected from voter registration lists for the two Vermont rural communities, and the 2000 census list of residents of Medford. The final survey was mailed out from November 2003 to February 2004. It was 13 pages, and consisted entirely of questions with set response categories, with the exception of one open-ended demographic question. In accordance with the Dillman technique[19] a sequence of up to four mailings went out to each respondent in an attempt to achieve the highest possible response rate. Potential respondents were informed that a $5 donation would be made to a local organization (senior center, recreation committee or friends of the public library) for each survey that was returned. All phases of this study were approved in advance by the institutional review panel at Tufts University, for the protection of human subjects.

The samples

Twenty people participated in the focus groups in Vermont and Massachusetts and 27 people participated in the individual interviews in Vermont, Massachusetts, Maine, New Hampshire and Connecticut. They ranged in age from 21 to 74, were predominantly female (74%), and predominantly white (85%). They lived in diverse locations, with their place of residence described as everything from 'farm' to 'urban'. Annual gross household income ranged from the lowest category of 'less than $5000' to the highest category of '$75,000 or more'. Twenty-eight percent of the respondents lived in households where incomes were under $30,000 per year. All but one participant had at least

a high school education, and 30 participants had four or more years of higher education.

For the 372 people who returned the mail survey (38% response rate for delivered surveys), most answered all of the demographics questions. Of those who responded, 71% were female. Mean age for the sample was 54, with age ranging from 21 to 89. Twenty-one percent of the households had one adult, 61% had two adults, and 18% had between three and six adults. Thirty percent of the households had children. The sample was predominantly white non-Hispanic (95%). Respondents were given five pre-determined residence categories and asked to indicate which category best reflected where they lived. Six percent of respondents marked 'farm' as their place of residence, 19% marked 'isolated rural', 31% marked 'small/large town', 17% marked 'suburban' and 26% marked 'urban'.

Nine income categories were provided. Twenty-six percent were in one of the first four categories (< $5000 to $20,000–$29,000), 30% were in the next two categories ($30,000–$39,999 to $40,000–$49,999), 25% were in the next category ($50,000–$74,999), and 19% were in one of the highest two categories ($75,000–$99,999 to $100,000 or more). Respondents had diverse educational backgrounds. Six percent of respondents had not completed high school, 32% had a high school degree or GED, 28% had 1–3 years of college, 19% had four years of college, and almost 15% had advanced degrees. Sixty-five percent were employed either full-time or part-time, and 35% were not employed. Types of jobs spanned the nine job categories defined by the US census. These categories are: (1) officials and managers, (2) professionals, (3) technicians, (4) sales workers, (5) administrative support workers, (6) craft workers, (7) operatives, (8) laborers and helpers, and (9) service workers[20].

Results

Views of scale and buying local

Focus group and individual interview participants were asked about their perceptions regarding industrialization of the food system, including the influence of the consumer in defining the future of the system. There were strong feelings expressed about this issue by many participants. This section depicts these views.

In general, respondents associated agri-business with many negative outcomes. Examples of those experienced primarily by the consumer were loss of control over one's diet and loss of options in the supermarket. Additional negative outcomes included loss of connection between the producer and the consumer, bad labor practices, greater chance of carelessness or mistakes 'in the process', and increased need for pesticides. This negative association with agri-business included a negative feeling about large farms. For example, one respondent indicated:

> 'What's the difference between the conventional food grower and the organic food grower? Well, the conventional food grower for the most part isn't a person anymore. It's a corporation'. (II, male, age 46)

Another said:

> 'When I think of organic I think more of actually the people. I think more of the earth, farming, what people are doing in fact to grow organic foods. When I think of non-organic, I think of more, you know, mechanics, production, bigger business, even though organic foods is a big business too, I'm sure. Yet it seems more community or small farms'. (II, female, age 44)

Although none of the respondents in any of the focus groups spoke about large-scale business in a positive way, some respondents did express empathy for the farmers who feel forced to either get bigger or give up. One focus group respondent described the desperate situation of some small-scale farmers by saying:

> 'They raise cattle and they raise chickens. They're very poor. Their barns are caving in. They have their livestock all squeezed in somewhere. I mean, it's really, really pathetic. It really is . . . it's poverty. I'm talking about poverty. That's what I'm talking about with small farmers'. (OFG)

The following sequence of comments made about dairy farming by two participants reflects their understanding of the need to grow larger to survive:

> 'Most of them are milking three times a day just to get their milk products out. There's such a low price on them and they're milking 300, 400 head'. (NOFG)

> 'The one that had the little 30 cows, they're gone, they're history. They got gobbled up'. (NOFG)

In summary, although respondents consistently expressed negative feelings about large-scale business, including farming, they expressed an understanding of the reasons that small-scale producers grow to survive.

Views of buying locally produced foods

In both the focus groups and individual interviews, buying foods produced locally was a frequently mentioned concept that was almost always framed in positive terms. Aspects of local purchasing that were mentioned included buying at farmers' markets, having farms in the city, and getting food that is fresh. One respondent also mentioned a desire to have large supermarkets sell more local products. While she indicated she would prefer lots of small shops, she did not think she would have the time to shop at them. (II, female, age 46)

Although no explicit attempt was made to have respondents define what 'local' meant to them, one organic buyer suggested there was something 'between' organic and conventional. Upon further questioning, the respondent said *'I think that's what local is. Like I don't worry as much if it doesn't say organic lettuce, but if it says it was grown locally, I figure they won't have to use too much amendments'. (OFG)*

Respondents provided some interesting perspectives on the many advantages of local food. In particular, they emphasized safety and familiarity as valuable attributes of local. The following is a sampling of comments that implied local was safer.

> 'I think if it's grown locally, it has that safe label, you know, you feel comfortable even if you don't know the person that grew it, but because they are in the area, and pretty much get known by everybody else'. (OFG)

> 'I think local is more safe. I don't think the issue is organic versus conventional. It's more like how many hands have been involved in that food, getting it to me'. (MFG)

> 'Already beef producers in Vermont are sending their meat out of state to get slaughtered because there aren't the slaughterhouses to handle the load. I wonder, again, it's how close are you to your food? And the further away it goes, the more doubt in my mind about its integrity as an organic food. The closer it stays, the stronger my belief is that it's maintained that integrity'. (OFG)

However, this view of increased safety was not shared by all respondents.

> 'So, although I like him, and I like the attempt he made, I think I'd actually rather have an organic strawberry from California than to buy strawberries that I know he used chemical fertilizers on, cause I know they're heavy feeders'. (OFG)

Similarly, a respondent who was focused on her children commented, when asked about choosing local versus organic, that her choice would depend on what her child was going to eat. If her child was '*going to eat a lot of it*,' she stated she would '*probably buy the organic*'. *(MFG)*

The importance of familiarity was expressed in different ways by various respondents.

> 'I feel guilty if I don't buy something that was grown in Vermont. This isn't organic, but if I don't buy Cabot butter, I feel guilty. I've got to buy Cabot. This is Vermont. We've got a town named Cabot. All these streets named Cabot'. (OFG)

> 'I don't compromise with cheese. I just like to support the local people. Well, Vermont is about cheese more than it's about other stuff'. (NOFG)

> 'If I see the farmer I'll buy his conventionally produced stuff almost for sure'. (MFG)

Merging understanding of local, small-scale and organic

Comments made both in focus groups and in individual interviews made it apparent that the concepts of local, small-scale and organic were often blended in people's minds. In other words, the view of organic farming was often imbued with attributes of local and small-scale approaches, making it difficult to differentiate the extent to which people's preference for organic related to elements of local and small-scale farming that are not in the formal definition of organic, and do not necessarily reflect the reality of organic in some locations.

The following quotations provide evidence of the ways in which small-scale and organic were often undifferentiated in respondents' minds. In these examples, the beneficial attributes of small-scale, organically produced foods relate to different taste of the food product, avoiding worker exploitation, and farm worker safety.

> 'Well, because organic meat as I'm defining it for you tends to be raised on smaller farms, by smaller operations, I think there is a significant difference. I've had some that my friend has given me, and it's very different tasting, really different'. (II, female, age 46)

> 'I associate organic with smaller, and I know I've heard that some of the larger farms are becoming organic, but ... smaller farmers you would think would have more safety for their workers. And they would have fewer workers. The larger farms, I think, again, is run by a larger corporation that's not so personable, so I think that you lose some of that'. (II, female, age 52)

Similarly, respondents integrated the concepts of local and organic in one breath, as noted in the following quotes:

> 'I just think one word that I wish I had associated, which in a way I did with organic, is local ... It seems to me it makes more sense to buy local because they don't use preservatives to make things last forever, without taste'. (OFG)

> 'If we thought that if we all bought organic that would feed all the local growers, and would in turn make the local economy strong, and if it would help save the planet from poisoning our water and everything else ...' (NOFG)

Although there was the tendency to merge the concepts of local and organic, one respondent specified that it depended on where you shopped. '*Not organic in the grocery stores. There are organic sources locally, but you can't get it in grocery stores*'. *(MFG)*

In an attempt to understand the extent to which respondents differentiated the benefits of organic versus local or small-scale, some respondents in individual interviews were asked which product they would choose if they were faced with a local, non-organic product, and an organic, non-local product. The product grown locally and/or on a small farm often won out over the organic product, as seen in the following quotes:

> 'To me I can have a much more positive impact by supporting local farmers than I can by supporting an organic farmer at a distance and I think the impact on my own health by consuming a non-organic product is probably minimal. So it's worth it to me. I'd rather have a farmer nearby have a negligible impact on my health than lose the farm'. (II, female, age 44)

> 'I'd probably go with the small farmer. I probably wouldn't even ask him if he was organic. See, I don't even ask them ... of course it also depends on price, and looks. It depends on the product'. (II, female, age 52)

However, the ideal combined organic with either local or small-scale, as described by one person who commented that '*organic has more value when I associate it with my*

neighbor, versus someone across the country'. (*II, female, age 62*)

Because the interviews in the qualitative component of this research identified a lack of differentiation of concepts when consumers thought about advantages of buying food produced on organic, small and local farms, we were interested in seeing if the mail survey would show that a broader group of consumers saw distinctions in these farming practices and related food products.

To test this, we asked the mail survey respondents to indicate how important each of 16 possible reasons to buy from each farm category was to them, if they actually bought from that farm category. There were four response choices for each reason, which included 'not important to me', 'mildly important to me', 'moderately important to me', and 'very important to me'. The 16 reasons provided were the same regardless of whether the question was referring to organic, small or local farms (see Table 3 for the list of possible reasons). This resulted in a total of 48 responses from each respondent (16 questions for each of three farm categories).

For all statistical analyses completed on mail survey data, we did not choose an *a priori* statistical significance level for our quantitative data. Instead, we chose to report actual *P*-values. All data analyses were performed using SPSS version 12.0 (SPSS Inc., Chicago, Illinois, USA).

Of the 372 respondents, 102 indicated they bought from all three categories of farms. However, only 86 of these answered all 48 questions. We used a two-way ANOVA with 86 replicates to assess whether there appeared to be an overall effect of the farm category. In other words, were respondents providing similar answers regardless of whether they were addressing their reasons for buying from a local farm, a small farm or an organic farm? The results (see Table 2) show a relationship between farm category and the questions ($F_{(2,8821)} = 2.41$; $P = 0.09$), indicating that people were providing different responses based on farm category, but the differences were not substantial. The differences in responses across questions were evident ($F_{(15,8821)} = 102.82$; $P < 0.001$). The interaction between farm category and the question was apparent as well ($F_{(30,8821)} = 1.92$; $P = 0.002$). Further analysis using *post hoc* repeated measures provided insight into where the greatest differences were between respondents' views on the importance of various reasons to buy food from each of the farm categories, as seen in Table 3. The sample size is greater than 86 for each of these questions because an individual's set of responses was included if the individual bought from all three categories of farms, and answered the particular question for each of the three farm categories. The six questions for which the differences across farm categories had the lowest *P*-values were related to the following topics: environment, rural economy, rural landscape, farmers, product freshness and product taste. Although there were differences across means, the differences were small.

Table 2. Two-way ANOVA of responses to 16 questions about three farm categories.

Source	SS	df	MS	*F*	*P*-value
Farm category	4.19	2	2.10	2.41	0.09
Question	1342.52	15	89.50	102.82	< 0.001
Interaction	50.23	30	1.67	1.92	0.002
Error	7678.06	8821	0.87		

One possible reason for respondents providing similar answers to each of the 16 questions described in Table 3 is that they did not necessarily see the three farm categories as distinct. To better understand the extent to which this was the case, we asked respondents to indicate whether they thought that 'organic farms tend to be smaller than average', and whether 'organic farms sell most of their products locally'. Two hundred and twenty-four respondents either strongly agreed or somewhat agreed that organic farms tend to be smaller than average. One hundred and ninety respondents either strongly agreed or somewhat agreed that organic farms sell most of their products locally.

Given our interest in understanding how respondents compared organic to small-scale, we examined paired samples *t*-tests for the responses to the 16 statements listed in Table 3 for all respondents who bought from organic and small farms. Of the 16 statements, the responses to five of the statements had *P*-values that were much lower than the rest. These differences related to the environment, rural landscape, farmers, farmers' markets and safety of the food, as shown in Table 4. Responses to three of these five statements resulted in higher means for small farms than for organic farms. 'Because of the environment' and 'safety of the food' were the reasons that had higher means for organic farms than for small farms.

Using responses from shoppers who indicated they buy food produced on organic farms as well as on local farms, we examined paired sample *t*-tests for responses to the 16 statements in the same fashion as described above. There were very low *P*-values (< 0.01) in analyses of respondents' reasons for buying from organic versus local farms for statements relating to impact on the rural economy, contribution to the rural landscape, wanting to support local farmers, food freshness, food taste and going to the farmers' market (Table 5). In all of these categories, the mean response was higher for this being a reason to buy from local farms rather than organic farms.

In summary, people who bought from all three farm categories were more likely to state 'impact on the environment' and 'safety of the food' as more important to them when buying from organic, compared to buying from a local or small farm. However, consumers placed slightly greater importance on a number of other reasons to buy from local or small-scale, compared to organic, but none of the reasons stood out as being that much more important.

Table 3. Shoppers' reasons for buying from organic, local and small farms.

I buy food on this category of farm because of the ...	Organic farm Mean (SD)	Local farm Mean (SD)	Small farm Mean (SD)	*n*	*P*
Environment	3.18 (± 0.87)	3.07 (± 0.95)	3.01 (± 0.89)	100	0.01
Treatment of farm workers	2.69 (± 0.96)	2.73 (± 0.99)	2.63 (± 0.97)	99	0.18
Impact on wildlife	2.81 (± 1.03)	2.78 (± 1.01)	2.77 (± 1.03)	97	0.77
Impact on the rural economy	3.17 (± 0.90)	3.37 (± 0.84)	3.23 (± 0.92)	100	0.01
Nutritional quality of the food	3.61 (± 0.74)	3.58 (± 0.77)	3.59 (± 0.78)	100	0.86
Safety of the food	3.64 (± 0.71)	3.56 (± 0.77)	3.53 (± 0.77)	99	0.08
Contribution to the rural landscape	2.93 (± 1.02)	3.13 (± 1.00)	3.07 (± .1.02)	99	0.01
Other farms have too much money and power	2.48 (± 1.19)	2.50 (± 1.14)	2.49 (± 1.15)	96	0.96
Animal treatment	2.87 (± 1.02)	2.89 (± 1.05)	2.84 (± 1.06)	97	0.70
Farmers I like to support	3.26 (± 0.91)	3.65 (± 0.64)	3.48 (± 0.79)	102	< 0.001
Amount of energy/fossil fuel used on this category of farm	2.69 (± 1.04)	2.68 (± 1.05)	2.64 (± 1.08)	98	0.67
Food's freshness	3.71 (± 0.61)	3.82 (± 0.50)	3.73 (± 0.65)	101	0.03
Food's taste	3.67 (± 0.65)	3.77 (± 0.55)	3.69 (± 0.64)	101	0.02
Farmers' market where I like to go for these products	3.20 (± 0.94)	3.31 (± 0.89)	3.27 (± 0.92)	99	0.08
Price of the food	2.57 (± 0.90)	2.65 (± 0.90)	2.64 (± 0.87)	99	0.34
[Increased chance] we will have enough food in the future	2.98 (± 1.00)	3.02 (± 0.98)	2.89 (± 1.05)	97	0.08

Table 4. Shoppers' reasons for buying from organic versus small farms.

I buy food on this category of farm because of the ...	Organic farm Mean (SD)	Small farm Mean (SD)	*n*	*P*
Environment	3.17 (± 0.86)	3.01 (± 0.89)	106	0.004
Treatment of farm workers	2.68 (± 0.95)	2.63 (± 0.97)	103	0.36
Impact on wildlife	2.83 (± 1.02)	2.80 (± 1.01)	102	0.60
Impact on the rural economy	3.16 (± 0.91)	3.22 (± 0.93)	106	0.38
Nutritional quality of the food	3.63 (± 0.72)	3.61 (± 0.77)	105	0.67
Safety of the food	3.64 (± 0.70)	3.54 (± 0.76)	103	0.07
Contribution to the rural landscape	2.90 (± 1.03)	3.08 (± 1.03)	104	0.004
Other farms have too much money and power	2.49 (± 1.18)	2.53 (± 1.15)	100	0.49
Animal treatment	2.90 (± 1.01)	2.87 (± 1.05)	101	0.55
Farmers I like to support	3.28 (± 0.89)	3.48 (± 0.79)	108	0.001
Amount of energy/fossil fuel used on this category of farm	2.71 (± 1.03)	2.66 (± 1.07)	102	0.39
Food's freshness	3.73 (± 0.59)	3.75 (± 0.63)	108	0.66
Food's taste	3.67 (± 0.64)	3.71 (± 0.63)	107	0.37
Farmers' market where I like to go for these products	3.22 (± 0.92)	3.30 (± 0.91)	105	0.03
Price of the food	2.58 (± 0.89)	2.66 (± 0.88)	104	0.12
[Increased chance] we will have enough food in the future	3.00 (± 0.98)	2.92 (± 1.04)	102	0.25

Conclusions

Consumers represented in this research tended to have very positive associations with local and small-scale farming. Although many of them similarly had positive associations with organic farming, some of what they valued in organic farms related to the fact that they tend to be smaller, and that they frequently sell their products locally. In recent years, across the country, there appears to be somewhat of a shift away from the perception that organic is predominantly local and small-scale[21]. While it is true that organic farms in both Vermont and Massachusetts, on average, are smaller than the average organic farm in the country, Vermont organic farms are not that much smaller, and the non-organic farms in these two states are also significantly smaller than in the nation[12]. Organic farms in Vermont are, on average, 60% of the size of non-organic Vermont farms, whereas organic farms in Massachusetts are, on average, 26% of the size of non-organic Massachusetts farms, and nationally organic farms are, on average, 29% of the size of non-organic farms[12]. While it is understandable that organic is conflated with small by many consumers in the Northeast, in reality, the strength of the association is variable.

Table 5. Shoppers' reasons for buying food from organic versus local farms.

I buy food on this category of farm because of the ...	Organic farm Mean (SD)	Local farm Mean (SD)	*n*	*P*
Environment	3.10 (± 0.89)	3.02 (± 0.96)	115	0.19
Treatment of farm workers	2.64 (± 0.98)	2.68 (± 1.02)	114	0.56
Impact on wildlife	2.72 (± 1.06)	2.72 (± 1.05)	111	1.0
Impact on the rural economy	3.11 (± 0.92)	3.34 (± 0.87)	115	<0.001
Nutritional quality of the food	3.57 (± 0.77)	3.55 (± 0.80)	114	0.74
Safety of the food	3.60 (± 0.75)	3.53 (± 0.80)	112	0.10
Contribution to the rural landscape	2.81 (± 1.05)	3.05 (± 1.03)	113	0.001
Other farms have too much money and power	2.45 (± 1.19)	2.42 (± 1.15)	109	0.69
Animal treatment	2.85 (± 1.03)	2.85 (± 1.07)	111	1.0
Farmers I like to support	3.20 (± 0.95)	3.59 (± 0.71)	116	<0.001
Amount of energy/fossil fuel used on this category of farm	2.62 (± 1.06)	2.63 (± 1.07)	111	0.85
Food's freshness	3.71 (± 0.63)	3.81 (± 0.51)	117	0.01
Food's taste	3.66 (± 0.68)	3.76 (± 0.57)	117	0.01
Farmers' market where I like to go for these products	3.09 (± 1.00)	3.22 (± 0.95)	114	0.005
Price of the food	2.57 (± 0.92)	2.65 (± 0.89)	113	0.16
[Increased chance] we will have enough food in the future	2.89 (± 1.04)	2.94 (± 1.01)	109	0.31

The challenge for the small-scale, local, organic producer will be to continue to hold the consumer's attention if and when the general perception of organic farming shifts to a more industrialized model. As further evidence of the importance of retaining the image of 'local' in 'organic', a study of 500 consumers in the Midwest (Nebraska, Iowa, Missouri and Wisconsin) found that 58% of those who had not purchased organic said they could be influenced to purchase 'locally grown organic'. In this Midwestern study, the attribute 'locally grown' was consistently ranked higher as a reason to make a food purchase, compared to the reason 'product is organic'[9].

Although responses in our mail survey showed only small differences in beliefs about what organic, small and local farms offer, it is interesting to look closely at what consumers said were the most important reasons to buy food produced on these farms. Freshness, taste, nutritional quality and safety were some of the most compelling reasons attributed to all three farm categories. Promoting these qualities in organic products would likely be advantageous. While the superiority of organic products in regard to nutritional quality and safety has not been scientifically confirmed, farmers can say their products are nutritious without offering a comparison to non-organic products.

When stating the importance of different reasons to buy from local, small or organic farms, respondents in our mail survey tended to attribute greater importance to various reasons to buy from local farms, as compared to organic or small farms. In looking back at comments made during focus groups and individual interviews, it seems as though there is a certain degree of pride and familiarity associated with local that was not equated as much with small-scale and organic, and could not be accurately captured in any one of our response categories on the mail survey. For example, when one respondent spoke of the streets and towns that have the same name as a Vermont cheese, it was almost as though the cheese was a reflection of the community, and therefore connected to the respondent's own identity. This may help explain the strong positive feelings that so many consumers have for locally produced foods.

Although consumers seem to be searching for the 'ideal' food product, some comments in our focus groups and individual interviews suggest that they understand that farmers have to make difficult choices for their businesses to survive, and their choices may not always give priority to consumers' preferences. What is less clear is whether consumers can hold this awareness when they are making food choices in the marketplace, or whether awareness dissipates when they are faced with real options.

Limitations of the Research

The research was carried out in just one region of the country, so generalizations outside of New England need to be made cautiously. Voter registration lists were the source of names for the mail survey in two communities. Because only 77% of adults in the US are registered to vote[22], these lists do not include all people who could have participated in the written survey. Additionally, given the 38% response rate to the survey, it is possible that non-respondents were different in some way than respondents. Furthermore, only 21% of the written survey sample was included in the analysis represented in Table 2 given their food shopping habits. The qualitative data was collected prior to October 2002, when the National Organic Standards became law. The written survey was completed after the standards became law. It is possible that consumer awareness about certain topics shifted between phases of this research.

Implications for Further Research

Given the changes that have occurred in organic food production in recent years, it is possible that consumer perceptions are similarly shifting. Future research that continues to track consumer views about the importance of scale and locality to organic food purchases would be useful, as well as research that assesses consumer perspectives in different regions of the country. Considering this research in the context of the actual organic farm size in various locations, as well as actual sales of local foods, would be particularly useful. In other words, it would be useful to explore whether a shift in consumer perspectives in a particular region is consistent with a shift in the scale of organic farms and the degree to which organic products are marketed locally.

It would also be of interest to know whether consumer views about scale and the location of production differ by organic product category, and whether this is dependent on region. Our qualitative research highlighted some ways that this was the case for a small number of respondents, but we were unable to test this in our mail survey.

As a point of reference for understanding consumer views, it would be valuable to know what percent of locally marketed food is produced organically. Again, this is likely to differ by region of the country, but is sure to have an influence on consumer views.

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The profitability of organic soybean production

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Abstract

Results from long-term experimental trials suggest that similar yields and lower costs are possible with organic compared to conventional soybeans, but there is little information about the relative costs and returns of these systems on commercial farms. This study examines the profitability of commercial soybean production using a nationwide survey of soybean producers for 2006 that includes a targeted sample of organic growers. Treatment-effect models are specified to characterize adopters of the organic approach and to isolate the impact of organic choice on operating, operating and capital, and total economic costs of soybean production. Organic soybean producers tend to be younger, have less crop acreage, and are less likely to work off-farm than conventional producers. Organic soybean production costs range from about $1 to $6 per bushel higher than those for conventional soybeans due to both lower yields and higher per-acre costs, while the average organic price premium in 2006 was more than $9 per bushel. Long-term cropping systems data suggest significant returns to organic systems result from similar yields and lower costs than conventional systems, but the high returns to commercial organic production found in this study can only be attributed to the significant price premiums paid for organic soybeans. Average organic soybean price premiums have remained high since 2006 despite much higher conventional soybean prices as users of organic soybeans attempt to retain and attract more acreage. However, increases in conventional soybean prices and fuel prices reduce the incentive for planting organic soybeans by improving returns to conventional production and increasing the relative costs of organic production.

Key words: organic, soybeans, profitability, price premium, treatment-effect model

Introduction

Organic cropping systems rely on ecologically based practices, such as biological pest management and composting, and the exclusion of synthetic chemicals. Under organic cropping systems, the fundamental components and natural processes of ecosystems—such as soil organism activities, nutrient cycling and species distribution and competition—are used as farm management tools[1]. For example, crops are rotated, food and shelter are provided for the predators and parasites of crop pests, animal manure and crop residues are cycled, and planting/harvesting dates are carefully timed.

Crop acres under organic systems have grown rapidly during the past decade. Organic crop acres were more than 2.5 times higher in 2005 than in 1995, as acreage increased from 638,500 to more than 1.45 million[2]. As part of this growth, organic soybean acreage increased from less than 50,000 in 1995 to nearly 175,000 acres in 2001. However, increased supply, along with competition from China in both US and Japanese markets[3] lowered prices for organic soybeans and acreage fell 27% in 2002. After 2002 organic soybean acreage stabilized and was about 122,000 acres in 2005.

Despite interest in organic soybean production there is little information about the relative costs and returns of organic and conventional production on US farms, and the characteristics of farms that are choosing the organic approach. Previous research examines organic crop returns using data from long-term experimental trials[4–6], but little has been reported about the commercial production of organic crops. The general objective of this study is to utilize farm survey data on US soybean production for 2006

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in a comparison of conventional and organic systems. One objective is to describe characteristics of farms adopting the organic production approach and how these are related to the likelihood that a farm would choose an organic system. The second objective is to describe and contrast the costs of production for each system and to use these to determine the level of price premiums that make organic systems competitive with conventional systems. This is among the first studies to describe commercial organic soybean production across the major production area of the US and should be of interest to producers considering organic production and to end-users of organic soybeans.

Experimental Trials

Much of what is known about organic cropping systems stems from multidisciplinary research conducted with long-term experimental trials that compare the agronomic, economic and sometimes environmental performance of organic and conventional systems. The identical weather and soil conditions under which field experiments are conducted provide opportunities not possible with on-farm studies, such as replication, precise field measurements and long-term comparisons. In these types of studies, descriptive and analytical data are collected on crop yields and management practices, and the productivity, economic viability and, in some cases, the potential environmental impacts of different farming systems are statistically assessed.

Results of an economic analysis of organic cropping systems using data from 1999 to 2001 are reported from the Neely-Kinyon Long-Term Agroecological Research site in Iowa[4]. This study compares a conventional corn–soybean rotation with organic rotations that include corn, soybeans, oats and alfalfa. Both corn and soybean production costs are significantly higher in the conventional system compared to the organic systems mainly due to higher costs of chemical versus mechanical weed control, while crop yields are much the same. Results indicate that returns to corn and soybean production are significantly higher under the organic systems. Returns to land, labor and management are higher with the organic rotations regardless of whether an organic price premium is received. Sensitivity analysis of labor charges reveals that organic systems have higher returns even when labor is valued at $50 per hour.

Data from 22 years of experiments from the Rodale Institute Farming Systems Trial in Pennsylvania are used to compare conventional, organic animal and organic legume systems[7]. Crop yields are similar with each system during normal years, but are higher for two organic systems under drought conditions. Energy input use, including fuels for farm machinery, fertilizers, seeds and herbicides, is about 30% less under the organic systems. Net returns to the organic rotations, without price premiums, are similar to those for conventional rotations during typical years, but are less when the costs of transition years are included. However, the organic price premium required to equalize returns is only 10% above the conventional price, much lower than normal price premiums for organic grains.

Long-term cropping system data during 1990–99 are used to examine the relative profitability of organic cropping systems in southwestern Minnesota[5]. The research examines various corn, soybean, oats and alfalfa rotations and finds that even though crop yields are lower under the organic input strategy, so too are production costs in comparison to conventional strategies. As a result, the organic input strategy provides net returns that are not statistically different from those of conventional strategies without any organic price premium, and are significantly higher when historical organic price premiums are paid.

A similar analysis of organic and conventional crop rotations in the northern Great Plains of Canada is conducted with data from 1997 to 2000[8]. Wheat, barley, peas and forage crops are part of the rotations. Some organic cropping systems are found to be more profitable than conventional systems, but this is conditional on the price premium and cropping system. Also, there is as much variation in net returns within organic and conventional systems as between the two. When costs of transition are taken into account, organic rotations have higher returns relative to many conventional rotations with price premiums at their most likely level, but require higher premiums to compete with the most profitable conventional rotations.

Data from long-term field trials covering 1982–1995 in southeastern Pennsylvania are used to evaluate the net returns to organic and conventional rotations using corn, wheat, soybeans and forages[6]. Annual returns to organic rotations compare favorably with those of conventional rotations after the transition period, but high transition costs may not justify the use of organic systems in some cases. The organic rotations require much more family labor than conventional rotations. This could hinder organic adoption among farmers who primarily work off-farm because of the high opportunity cost of switching to organic farming that would result from foregone wages and benefits.

Long-term agricultural experiments are leading to an improved understanding of the main biophysical and economic processes associated with different farming systems, addressing basic research questions about yields, profitability and environmental impacts. In most of the situations studied, organic cropping systems generate economic returns equal to or greater than those of conventional systems, and sometimes much greater returns. Despite this progress, comparisons between conventional and organic cropping systems are problematic mainly because the latter employ unique approaches to nutrient availability, pest control and soil management that are profoundly different and may not be easily employed outside of the experimental setting. These experiments also leave out the 'human factor' – that valuable system of local knowledge and expertise that every farmer acquires through on-farm

experience and experiments that plays a crucial role in organic farming. This study enhances the long-term experimental literature by reporting on actual farmer experience with organic systems.

Data

Data used in this study come from on-farm measurements made in USDA's 2006 Agricultural Resource Management Survey (ARMS) administered by the National Agricultural Statistics Service and Economic Research Service. The ARMS data include detailed farm financial information, such as farm income, expenses, assets and debt, as well as farm and operator characteristics. Specifically, this study uses a version of the 2006 ARMS that includes detailed information about the production practices and costs of soybean production. This version targeted soybean producers in 19 states that include 97% of US planted soybean acreage in 2006.

The 2006 ARMS soybean version includes a sub-sample targeting organic acreage. Of the total soybean sample of 4557 farms, 907 samples targeted organic operations in 15 states as identified from lists provided by state organic certifiers. After accounting for non-response and missing data, 2209 farms are available for analysis, including 238 operations producing organic soybeans in 2006. Characteristics and production costs are compared among conventional and organic producers in Corn Belt and Midwest States. The sample from IL, IN, IA, KS, MI, MN, MO, NE, ND, OH, SD and WI include 1425 conventional and 237 organic producers. Farm survey weights on the ARMS data, proportional to the probability of selection, ensure that the sample expands to represent soybean acreage in each state and that organic operations represent their correct proportion of the population despite their disproportionate share of the sample.

Costs of organic and conventional soybean production are computed according to procedures used by USDA[9] and endorsed by the American Agricultural Economics Association[10]. Costs are computed per bushel and divided into three categories: operating costs, operating and capital costs, and total economic costs. Operating costs include costs for seed, fertilizer, chemicals, custom operations, fuel, lubrication, electricity, repairs, purchased irrigation water, hired labor and operating interest. Capital costs include the annualized cost of maintaining the capital (economic depreciation and interest) used in soybean production, and costs for non-real estate property taxes and insurance. Total economic costs are the sum of operating and capital costs, plus opportunity costs for unpaid labor and land, and allocated costs for general farm overhead items. Total operating costs is an indicator of the relative success of operations in terms of their ability to meet short-term financial obligations. The sum of operating and capital costs provides an indicator of whether operations can replace capital assets as needed and stay in business over time. Other costs are primarily opportunity costs of owned resources (land and labor) that may or may not influence production decisions. Opportunity costs of owned resources may vary significantly among producers and many producers are willing to accept returns to these resources different from assumed charges. Lifestyle preferences and costs of switching occupations, among others, affect producers' perceptions of their opportunity costs.

Survey Results

A summary of the ARMS data indicates that organic soybean production is conducted on smaller operations than conventional production. Conventional soybean producers harvest an average of 272 soybean acres as part of 748 acres in the farm operation, compared to 117 soybean acres on 478 farm acres by organic soybean producers (Table 1). Despite their smaller size, organic soybean producers are less likely to report off-farm employment as their major occupation (26 versus 16%). The average age of organic and conventional producers is much the same, but conventional producers are more likely to be over 65 (24 versus 14%). Significantly more of the conventional producers report a high school education (45 versus 24%). Interestingly, a higher proportion of organic producers have either not completed high school (18 versus 5%) or attended college (57 versus 50%), so there is no clear association between operator education and organic production. Organic producers are more often located in the northern states of MI, MN and WI in relation to the other Corn Belt and Midwest states included in the survey (51 versus 24%).

Production practices used in conventional and organic soybean production are much different. Nearly all conventional producers use genetically modified herbicide tolerant seed (97%), while most organic producers use clear hilum seed (68%). Clear hilum is a food-grade soybean most often used for soymilk and tofu. More than 90% of organic producers plant soybeans in standard rows, compared to 60% of conventional producers. This allows organic producers to cultivate for weed control an average of 1.5 times, while conventional producers rarely cultivate for weeds. Nearly 80% of conventional producers use a crop rotation (3 years) comprised of continuous row crops, whereas organic producers more often rotate soybeans with small grain and meadow crops (e.g., alfalfa and other hay), and 40% include an idle year in the rotation. Organic producers more often control pests by using intensive tillage practices as 36% report using a moldboard plow, while half of conventional producers use a no-till planter and rely on chemical pest control.

Average soybean operating costs per acre are not significantly different among conventional and organic producers, but their composition is very different (Table 2). Conventional production involves much higher chemical costs ($13.97 versus $0.02 per acre), while organic systems substitute field operations for chemicals and incur much higher fuel, repair and hired labor costs. Capital and other

Table 1. Test of equality of means on characteristics and practices of conventional and organic soybean farms, Corn Belt and Midwest, 2006.

Item	Type of farm: Conventional	Type of farm: Organic	*t*-stat
Farm characteristics			
Harvested soybean acres (per farm)	272	117	7.42
Farm acres operated (per farm)	748	478	4.41
Farm operator			
Off-farm occupation (percent of farms)	26	16	3.18
Age (years)	55	54	1.28
More than 65 years (percent of farms)	24	14	2.97
Education (percent of farms)			
Less than high school	5	18	1.73
Completed high school	46	24	3.86
Attended college	50	57	1.07
MI, MN or WI (percent of farms)	24	51	3.23
Soybean production practices			
Seed (percent of farms)			
GM herbicide tolerant	97	0	na
Organic clear hilum	0	68	na
Organic other food-grade	0	15	na
Organic non-food-grade	0	13	na
Other seed	3	5	1.52
Planted in standard rows	60	92	11.54
Crop rotation (percent of farms)			
Monoculture	4	1	2.58
Continuous row crop	79	19	12.15
Row crops and small grains	4	24	3.13
Idle year	9	40	3.76
Meadow crop	4	17	3.04
Field operations (percent of farms)			
Moldboard plow	5	36	4.53
No-till planter	50	6	14.89
Row cultivator	3	65	9.28
Times cultivated	0.03	1.53	6.04
Other practices (percent of farms)			
Irrigation	5	3	1.52
Applied commercial fertilizer	32	7	10.57
Applied manure or compost	7	28	3.08
Number of observations	1425	237	

Source: 2006 Agricultural Resource Management Survey, USDA National Agricultural Statistics Service and Economic Research Service.
Note: Statistical significance in test of equality of means is indicated by *t*-statistics greater than 1.96 and 1.65 at the 5 and 10% levels, respectively. na = not applicable.

Table 2. Test of equality of means on production costs and returns of conventional and organic soybean operations, Corn Belt and Midwest, 2006.

Item	Type of farm: Conventional	Type of farm: Organic	*t*-stat
	Dollars per planted acre		
Gross value of production	258.08	454.51	6.67
Operating costs			
Seed	32.06	30.41	1.33
Fertilizer	12.34	9.63	1.03
Chemicals	13.97	0.02	39.55
Custom operations	6.04	5.75	0.17
Fuel, lubrication and electricity	12.44	24.46	5.74
Repairs	11.40	17.57	2.80
Purchased irrigation water	0.10	0.05	1.15
Hired labor	1.20	12.82	2.71
Operating capital	2.13	2.39	1.09
Capital ownership costs			
Capital recovery	60.14	76.44	3.36
Taxes and insurance	8.10	14.19	2.46
Other costs			
Opportunity cost of unpaid labor	15.69	41.51	10.58
Opportunity cost of land	87.49	79.45	1.41
General farm overhead	13.32	25.90	3.44
Cost summary			
Operating costs	91.66	103.10	1.09
Operating and capital ownership costs	159.91	193.73	2.31
Total economic costs	276.40	340.59	4.13
Value of production less			
Operating costs	166.42	351.41	4.98
Operating and capital ownership costs	98.18	260.79	4.18
Total economic costs	−18.32	113.92	3.32
	Dollars per bushel		
Cost summary			
Operating costs	1.95	3.32	2.90
Operating and capital ownership costs	3.40	6.24	3.94
Total economic costs	5.87	10.97	5.36
Yield (bushels per planted acre)	47.06	31.04	8.63
Price (dollars per bushel)	5.48	14.64	27.24

Source: 2006 Agricultural Resource Management Survey, USDA National Agricultural Statistics Service and Economic Research Service.
Note: Statistical significance in test of equality of means is indicated by *t*-statistics greater than 1.96 and 1.65 at the 5 and 10% levels, respectively. na = not applicable.

costs are also much higher for organic production due to the greater use of field machinery and unpaid labor. The paid and unpaid labor costs for organic production total $54.33 per acre, compared to $16.89 for conventional production. Total operating and capital costs and total economic costs are significantly higher for organic production, averaging more than $30 and $60 per acre higher, respectively, than for conventional production.

Organic soybean producers have an average yield in 2006 that is significantly lower than that of conventional producers (31 versus 47 bushels per acre). With lower yields and higher per-acre costs, operating costs per bushel for organic producers are $1.37 higher than for conventional producers, operating and capital costs are nearly $3 higher and total economic costs are more than $5 higher. Production costs of food-grade and non-food-grade organic soybeans are not significantly different. The average price premium received by organic producers is more than $9 per bushel in 2006 ($14.64 versus $5.48 per bushel), much higher than the average difference in total economic costs. The average price received for food-grade soybeans ($15.08 per bushel) is significantly greater than that for non-food-grade soybeans ($12.48 per bushel).

Organic soybean producers report that they had been producing organic for an average of 8 years in 2006. The primary reason given for producing organic is to increase farm income, reported by 47% of farmers, while 44% are split almost evenly between the reasons of protecting family and community health and being more environmentally friendly. Forty-three percent of organic producers regard achieving desirable yields as the most difficult aspect of production, followed by 10% who consider distance to markets. Only 5% report sourcing inputs and just 2% indicate costs of inputs as the most difficult aspect of organic production.

Empirical Procedure

The identical weather and soil conditions and field management practices under which cropping system experiments are conducted have the advantage of precise field measurements that are not possible using producer survey data. When using on-farm data to measure cost differences between cropping systems, other factors that affect costs should be addressed. A simple comparison of the mean difference between conventional and organic production costs can be misleading because other differences, such as in farm size, location, other technologies and management, may also influence cost levels. To isolate the effect that choice of the organic approach has on production costs, a treatment-effect model is employed[11].

The model accounts for observable differences between organic and conventional production using the detailed data from the ARMS. Unobservable differences are addressed by assuming a joint normal distribution between the errors of a selection equation (choice of the organic approach or not) and treatment equations (measures of production costs). This technique corrects for sample-selection bias and allows for an unbiased estimate of the impact that choice of the organic approach has on production costs. For example, differences in the level or type of management are not observable but may influence both the choice between organic and conventional production and the level of production costs.

Applying the treatment-effect model, the decision to choose the organic approach or not can be expressed with the latent variable O_i^* indicating the net benefit from using this approach compared to not using, so that:

$$O_i^* = \mathbf{Z}_i\gamma + u_i, \quad \text{where } O_i = 1, \text{ if } O_i^* > 0, \text{ 0 otherwise,} \quad (1)$$

where $\mathbf{Z}_i$ is a vector of operator, farm and regional characteristics. If the latent variable is positive, then the variable indicating organic production O_i equals one, and equals zero otherwise. A measure of the impact of the organic approach on production costs y_i can be expressed by:

$$y_i = \mathbf{X}_i\beta + O_i\delta + \varepsilon_i, \quad (2)$$

where $\mathbf{X}_i$ is a vector of operator, farm and regional characteristics.

Equation (2) cannot be estimated directly because the decision to choose the organic approach may be determined by unobservable variables, such as management factors, that may also affect production costs. If this is the case, the error terms in equations (1) and (2) will be correlated, leading to a biased estimate of δ. This selection bias can be accounted for by assuming a joint normal error distribution with the following form:

$$\begin{bmatrix} u \\ \varepsilon \end{bmatrix} \sim N\left(\begin{bmatrix} 0 \\ 0 \end{bmatrix}, \begin{bmatrix} 1 & \rho \\ \rho & \sigma_\varepsilon^2 \end{bmatrix}\right)$$

and by recognizing that the expected cost of choosing the organic approach is given by:

$$E[y_i | O_i = 1] = \mathbf{X}_i\beta + \delta + \rho\sigma_\varepsilon\lambda_i, \quad (3)$$

where λ_i is the inverse Mills ratio. To derive an unbiased estimate of δ, the two-stage approach begins with a probit estimation of equation (1). In the second stage, estimates of γ are used to compute the inverse Mills ratio, which is included as an additional term in a least-squares estimation of equation (2). This two-stage Heckman procedure is consistent, albeit not efficient. Efficient maximum likelihood parameter estimates can be obtained by maximizing:

$$L(\gamma, \beta, \sigma, \rho) = \prod_{A_i = 0} \int_{-\infty}^{0} \int_{-\infty}^{\infty} f(A_i^*, y_i; \gamma, \beta, \sigma, \rho) \mathrm{d}y \, \mathrm{d}A^* \times \prod_{A_i = 1} \int_{0}^{\infty} \int_{-\infty}^{\infty} f(A_i^*, y_i; \gamma, \beta, \sigma, \rho) \mathrm{d}y \, \mathrm{d}A^*,$$

where $f(A_i^*, y_i; \gamma, \beta, \sigma, \rho)$ is the joint normal density function, which is a function of the parameters. In practice, the negative of the log of the likelihood function is minimized using the estimates from the Heckman procedure as starting values.

The model is specified using the three levels of production costs as the dependent variables: operating costs, operating and capital costs and total economic costs. The comprehensive nature of the ARMS provides data on a variety of operator, farm structural and financial, and enterprise characteristics that are used as independent variables.

Table 3. Binomial probit maximum likelihood estimates: choice of the organic production approach by soybean producers, Corn Belt and Midwest, 2006.

Variable description	Coefficient	Standard error
Constant	−2.6490**	0.1336
Size (100 acres operated)	−0.0389**	0.0137
Size squared	0.0002**	0.0001
Age class (< 50 years)	−0.0975	0.1223
Age class (>65 years)	−0.6130**	0.1850
Education class (less than high school)	0.8832**	0.2629
Education class (attended college)	0.3134**	0.0843
Primary occupation is off-farm	−0.3524**	0.1096
Livestock operation on farm	0.0929	0.0886
Location in MI, MN or WI	0.3472**	0.1075
Log likelihood	−38.6822	
Pseudo R^2	0.0942	

Note: Dependent variable in the probit equation is whether the farm produced organic soybeans (0, 1). * and ** denote statistical significance at the 10 and 5% levels, respectively.

Once estimated, the difference in costs between organic and conventional systems is determined by[11]:

$$E[y_i|\, O_i = 1] - E[y_i|\, O_i = 0] = \delta + \rho\sigma_\varepsilon \left[\frac{\phi_i}{\Phi_i(1-\Phi_i)}\right], \qquad (4)$$

where ϕ is the standard normal density function and Φ is the standard normal cumulative distribution function evaluated using the selection equation estimates.

Model Results

Estimates for a binomial probit model of choice of the organic approach by soybean producers are shown in Table 3. These estimates are nearly identical to those in the selection equations estimated in the treatment-effect models. Several coefficients estimated for farm operator characteristics are statistically significant. Operator age is specified with discrete categories with the age class of 50–65 years as the omitted group. The results indicate that the oldest farm operators, those more than 65 years old, are less likely to choose the organic approach than younger farmers. The oldest farm operators have fewer incentives to invest the financial and human capital resources necessary for organic production due to their shorter planning horizon. Operator education is also indicated with discrete categories, where high school graduates are the omitted group. These results reveal that both the most (those that attended college) and least (those not graduating from high school) educated are more likely to use the organic approach than high school graduates. Also, farm operators with a primary occupation off-farm are less likely to produce organic, perhaps because of the greater labor requirements of organic production.

Size of operation and location also play a role in choice of the organic approach. As operated farm acreage increases, the likelihood of choosing the organic approach declines (at a decreasing rate). This may be due to the additional labor requirement of organic production, but also to the potentially higher returns per acre for smaller farmers from producing a relatively high valued crop. Location in the northern states of MI, MN and WI is associated with the adoption of organic soybeans, possibly due to less weed pressure that facilitates organic production in these areas, or because of markets for organic feed ingredients due to significant organic milk production in these states.

Coefficients on farm operator characteristics are not statistically significant in the treatment-effect models of soybean production costs, but those for farm size, measured as harvested soybean acres, and location are significant (Table 4). Soybean operating, operating and capital, and total economic costs per bushel all decline as size increases with the largest impact of size on total economic costs. Total economic costs include charges for capital and labor whose fixed amounts are spread over more units on larger enterprises. Location in the states of MI, MN and WI is also associated with lower operating and capital and total economic costs of soybean production.

Several production practices have a statistically significant effect on soybean production costs. Crop rotations are specified with continuous row crop as the deleted group. Thus, coefficients on the rotation variables indicate that monoculture, row crop and small grain rotations, and row crop and idle rotations are all associated with higher production costs than a continuous row crop system. Irrigation and the use of commercial fertilizers are also associated with higher per bushel soybean production costs.

The coefficients in Table 4 on the variable for organic soybean production are used in equation (4) to estimate the difference in costs between organic and conventional soybean production, and thus the price premium required for organic production to be competitive with conventional production. The results indicate that operating costs for organic soybean production are $0.82 per bushel higher, operating and capital ownership costs are $2.19 per bushel higher and total economic costs are $5.20 per bushel higher in 2006, after accounting for the influence of other factors on production costs and potential sample selection bias. The estimated correlation of errors of the selection and cost equations, rho, is not statistically significant in any of the models, suggesting that selection bias is not a significant problem with the sample.

Transition Costs

The estimated cost differences indicate the additional costs incurred by operations producing organic soybeans relative to conventional soybeans, but do not include the costs associated with the transition to organic production. Before an operation is certified to sell organic soybeans the cropland must be managed organically for a minimum of 36

Table 4. Treatment-effect model maximum likelihood estimates: costs of soybean production, Corn Belt and Midwest, 2006.

Variable description	Operating costs Coefficient (std. error)	Operating and capital costs Coefficient (std. error)	Total economic costs Coefficient (std. error)
Constant	1.777** (0.491)	3.165** (0.787)	5.861** (1.15)
Age (years)	−0.001 (0.005)	−0.004 (0.009)	−0.005 (0.012)
Education (years)	0.170 (0.024)	0.041 (0.035)	0.078 (0.059)
Primary occupation is off-farm	0.013 (0.124)	−0.132 (0.195)	−0.141 (0.310)
Location in MI, MN or WI	−0.156 (0.123)	−0.347** (0.173)	−0.647** (0.268)
Size (harvested soybean acres)	−0.061** (0.023)	−0.054* (0.028)	−0.148** (0.062)
Size squared	0.001* (0.000)	0.001 (0.001)	0.003 (0.002)
Rotation-monoculture	1.261* (0.689)	1.700** (0.756)	1.968 (1.232)
Rotation-row crops and small grains	1.532** (0.425)	3.105** (0.784)	3.830** (1.140)
Rotation-row crops and idle	0.534** (0.203)	0.872** (0.365)	0.790 (0.531)
Rotation-row crop and meadow	0.183 (0.185)	0.281 (0.249)	0.235 (0.324)
No-till planter	0.088 (0.115)	0.048 (0.179)	0.000 (0.276)
Moldboard plow	0.593 (0.584)	0.843 (0.650)	2.190* (1.169)
Irrigation	0.655** (0.112)	1.182** (0.165)	0.903** (0.217)
Commercial fertilizer	0.713** (0.120)	0.580** 0.165	0.552** (0.262)
Manure	0.275* (0.167)	−0.006 (0.179)	−0.422* (0.254)
Organic	0.756* (0.406)	2.034** (0.665)	5.024** (1.008)
Sigma	1.585** (0.193)	2.571** (0.332)	3.906** (0.520)
Rho	0.013 (0.033)	0.019 (0.021)	0.014 (0.019)
Log likelihood	−43,4957	−54,5484	−64,1014

Note: Dependent variables in each equation are the operating, operating and capital, and total economic costs per bushel of soybean production, respectively. * and ** denote statistical significance at the 10 and 5% levels, respectively.

months. This means that operations must undergo 3 years of higher costs before selling soybeans as certified organic.

Higher costs for 3 years can be considered as an investment necessary to return higher soybean prices over the expected life of the operation. The investment is determined by the estimated additional costs incurred by organic operations from the treatment-effect model for each year of the 3-year transition period. The annualized cost of this investment is computed using the capital recovery approach like the other capital costs[10]. The investment is spread over an expected life of 20 years.

The estimated transition costs and total additional costs on organic operations are shown in Table 5. Transition costs are $0.42 per bushel for operating and capital costs and $1.00 per bushel for total economic costs. Thus, the total estimated additional costs for producing organic relative to conventional soybeans are $0.82 per bushel for operating costs, $2.61 per bushel for operating and capital costs and $6.20 per bushel for total economic costs.

Table 5. Additional costs incurred for organic soybean production in relation to conventional soybean production, 2006.

	Operating costs	Operating and capital costs	Total economic costs
	----------Dollars per bushel----------		
Additional costs from			
Producing organic	0.82	2.19	5.20
Transitioning to organic	na	0.42	1.00
Total additional costs	0.82	2.61	6.20

Note: Transition costs are treated as a capital investment necessary to return the higher organic soybean price over the expected life of the operation and thus are not part of annual operating costs. na = not applicable.

Conclusions

This study takes advantage of unique and detailed data from a survey of US soybean production for 2006. The data are unique in that they include a targeted survey of organic producers sampled at a much higher rate than their occurrence in the population. This allows for a statistical analysis of differences between conventional and organic crop production systems.

One objective of the study is to describe characteristics of farms adopting the organic production approach, and how these are related to the likelihood that a farm would choose an organic system. Size of operation is found to be one of the primary factors determining the likelihood of an operation using the organic approach. Because of economies of size, small farms likely view the organic approach as among the few alternatives to reorganize current resources to improve farm returns. Larger farms likely have less incentive to consider alternatives because of economies of size. Also, significant labor requirements associated with organic crop production may make organic production less practical on larger farms due to the need to hire additional labor, while the labor requirements on smaller farms are

often met by operator and other unpaid sources. Marketing opportunities for food-grade soybeans may also be influencing the choice of organic production. Producers are able to market food-grade soybean production and earn higher profits than with feed-grade production despite lower yields associated with food-grade varieties, as production costs for food and feed-grade soybeans are not significantly different and the average price for food-grade soybeans is higher. The average price for food-grade soybeans was $2.60 per bushel higher in 2006.

The second objective of the study is to describe and contrast the costs of production for each system and to use these to determine soybean price premiums that make organic systems competitive with conventional systems. The results indicate that the average operating costs for producing organic soybeans are $0.82 per bushel higher, operating and capital costs are $2.61 per bushel higher and total economic costs are $6.20 per bushel higher, after accounting for the influence of other factors on production costs, sample selection bias and organic transition costs. These higher costs compare to an average price premium of $9.16 per bushel for organic soybeans in 2006, suggesting that organic soybean producers, on average, earned returns above costs ranging from about $3 to $8 per bushel in 2006.

Previous research, based on long-term cropping system data, also suggests that significant returns are possible from organic soybean production. However, these returns are the result of obtaining similar conventional and organic yields and lower organic production costs, while findings of this study show organic yields to be much lower and production costs to be higher. Experimental trials often compare soybean varieties of a similar type, such as food-grade soybeans, whereas the surveyed conventional and organic producers use varieties that are much different. Food-grade soybeans, including the clear hilum beans used by most organic producers, have been shown to yield significantly less than a typical Roundup Ready® system used by conventional growers[12]. Another reason for the yield differences may be the unique problems presented from implementing organic systems outside of the experimental setting, such as achieving effective weed control. The reason that organic soybeans are more profitable in the analysis of the 2006 ARMS data is not from higher yields and lower costs, but rather from the significant price premiums paid for organic soybeans.

Historical price premiums for organic soybeans have generally been high in comparison to other major field crops. Organic soybean prices from 1995 to 2003 were 2–3 times higher than conventional prices[13], and an average price ratio of 2.67 is measured from the 2006 ARMS data. However, prices for conventional soybeans have increased dramatically since 2006. Soybean prices received by farmers that were $6.37 per bushel in January 2007 reached $13.00 per bushel in 2008 and remained above $9.00 per bushel into 2009[14]. Organic soybean prices also moved much higher, up to around $28 per bushel for food-grade soybeans in 2008, and nearly $22 per bushel into 2009[15].

Much higher organic soybean prices in 2008 and 2009 are a signal that users of organic soybeans are attempting to retain and attract more organic acreage. However, higher fuel prices in 2008 increased costs of producing organic more than conventional production because of more tillage and mechanical weed control in organic systems. Also, the improved profit potential of conventional soybean production may have reduced incentives to invest the additional capital and labor for organic production, endure the transition period, and to take the additional risks of producing organic. When conventional soybean prices and/or fuel costs are high, expansion of US organic soybean acreage may be limited despite significant price premiums and profit potential from organic production. In addition, recessionary conditions in 2009 may slow the growth in demand for organic products as consumers, particularly those that don't already purchase organic products, become less willing and able to pay organic price premiums.

While results of this study provide insight about the profitability of organic soybean production, the findings are based only on a single year of data. The production of organic soybeans, in contrast to conventional soybeans, is most often part of a multi-year rotation of several crop enterprises. Organic soybean producers may rotate with less profitable enterprises, lowering overall cropping system returns, or the synergism associated with the management of multiple crop enterprises may result in an even greater profit potential than indicated by this single-enterprise analysis. A more thorough study of the profitability of organic systems would account for the inherent multi-year nature of organic cropping systems.

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Nutritional and quality characteristics expressed in 31 perennial wheat breeding lines

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Abstract

Soil erosion due to annual cropping on highly erodible farmland is a major ecological concern in the wheat growing regions of Washington State. In response to requests from farmers, the winter wheat breeding program at Washington State University has been developing perennial wheat selected from crosses between wild wheatgrass species and commonly grown annual wheat cultivars. In 2005/06, we conducted field trials of the most promising perennial wheat breeding lines derived from interspecific crosses between tall wheatgrass (*Thinopyrum elongatum*) and bread wheat (*Triticum aestivum*). Thirty-one perennial breeding lines and two annual winter wheat cultivars were evaluated for nutritional value in the form of grain mineral concentration, multiple baking and milling quality traits, and ease of grain threshability. The objective of this study was to identify the strengths and weaknesses of these post-harvest traits in the perennial wheat lines derived from these interspecific crosses. Mineral nutrient concentrations in the perennial lines were 44, 40, 24, 23, 32, 30 and 33% higher than the annual control cultivars for calcium, copper, iron, magnesium, manganese, phosphorus and zinc, respectively. The annual cultivars had a higher grain mineral content per unit area of land than the perennial lines, due primarily to the higher grain yields of the annual cultivars. Compared to the annual wheat cultivars, the perennial lines produced grain with smaller seed size, lower test weight and reduced flour yield, mix time and loaf volume. Protein content was 3.5–4.5% higher in the perennial lines than in the annual cultivars. The threshability index (TI) ranged from 0.63 to 0.89 in the perennials ($\mu = 0.75$); significantly lower than the mean TI of the annual cultivars ($\mu = 0.97$). The significant genotype × location interaction found for TI suggests that the variation in annual precipitation positively influenced some perennial lines to express greater threshability. In addition to transferring traits important to the perennial growth habit in wheat, the wild wheatgrass species also introduced beneficial characteristics (i.e. increased protein and mineral concentration) and deleterious traits (poor threshing grain and inferior baking qualities). This research gives researchers a platform from which to direct further research and selection in the development of perennial wheat.

Key words: perennial grains, wheat, agroecology, yield, mineral concentration, specialty crops, protein, threshability

Advances in cereal-based agricultural systems over the 40-year period from 1960 to 2000 helped to effectively reduce the global percentage of chronically malnourished people from 60 to 17%[1]. The elevated yields inherent in these high-input 'Green Revolution' systems also alleviated ecological land-use problems by reportedly keeping 1.2 billion hectares of largely fragile ecosystems out of agricultural production[1]. However, modern farming systems based on annual cropping systems are widely considered to be a contributing factor to multiple environmental problems, including the loss of genetic diversity and biological diversity, soil erosion and pollution from fertilizers and pesticides[2,3]. For example, coastal dead zones, exacerbated by runoff of nitrogenous fertilizers, have spread exponentially since the 1960s, the beginning of the Green Revolution era, and now total over 245,000 km^2 in area[3]. Additionally, water erosion alone causes approximately 31.5 $t\,ha^{-1}$ of soil loss per year in wheat-based cropping systems in the Palouse region of Washington State[4]. Due to the potential ecological benefits of growing perennial-based

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cereals as a solution to these global agroecological problems, research into the development and agronomic production of perennial cereal crops is emerging across the US, China and Australia[5–7].

The large increases in the percentage of people suffering from micronutrient malnutrition over the past four decades coincide with the global expansion of high-yielding, input-responsive cereal cultivars[8,9]. Although grain yields have significantly increased post-Green Revolution, global food systems are not providing people with sufficient micronutrients[9–12]. Currently, over 40% of the world's population is micronutrient deficient; the dietary intake of iron (Fe) of more than two billion people worldwide is inadequate[13–17]. Notably, the mineral concentration of annual wheat varieties has shown a steady general decline over the past 50+ years[18].

Improving the nutritional value of wheat has potential to be realized through wide crosses utilizing wild wheatgrass species[19–22]. Although this study focuses on perennial wheat lines with *Thinopyrum elongatum* in the pedigree, multiple wild species in addition to *T. elongatum* can be used as parents in the development of perennial wheat. These species can be chosen based on chromosome number, and on traits including local adaptation, disease resistance, drought tolerance and growth habit[23]. Wild relatives of wheat confer beneficial characteristics to the development of perennial wheat; however, they can also be a source of negative traits, particularly those relating to end-use quality and grain threshability.

In addition to addressing the important agronomic traits of grain yield and regrowth after harvest, challenges inherent in the development of perennial wheat include selection of cultivars with enhanced nutritional value, acceptable baking and milling quality and free threshing grain. The objectives of this study were to evaluate grain concentration of calcium (Ca), copper (Cu), iron (Fe), magnesium (Mg), manganese (Mn), phosphorus (P) and zinc (Zn); several end-use quality traits important to baking and milling properties; and grain threshability in 31 perennial wheat lines and two annual wheat cultivars in three locations in Washington State. Each location represents a potential target environment for perennial wheat due to excessive soil loss from wind and/or water erosion. We discuss aspects of the current state of perennial wheat development and identify key traits to target for genetic improvement.

Materials and Methods

Mineral and quality analyses

Mineral analyses of Ca, Cu, Fe, Mg, Mn, P and Zn were performed at the Grand Forks Human Nutrition Research Center in North Dakota using methods reported by Murphy et al.[18]. Mineral analyses were conducted on all genotypes at each location. End-use quality traits, including test weight, kernel hardness and whole wheat protein were measured on all perennial lines from each location post-harvest according to AACC Approved Methods 55-10, 55-31 and 46-30, respectively[24]. Quality traits including flour yield, flour ash, flour protein, mixograph absorption, mixing time and loaf volume of pan bread were determined on both annual wheat cultivars and on five randomly chosen perennial breeding lines from Ritzville and Pullman. Ash and protein content, mixograph absorption, mixing time and bread baking quality were determined according to AACC Approved Methods 08-01, 46-30, 54-40A and 10-10B, respectively[24]. Seed size and weight were measured on all lines in Kahlotus and Ritzville. Kernel hardness was tested on all genotypes at each location and test weight was evaluated at Ritzville and Pullman.

Experimental design

In this study, perennial is defined as a plant exhibiting post-sexual cycle regrowth for a minimum of two cycles[25]. All perennial lines used in this study were shown to be perennial in previous breeding trials. Thirty-one F_5 perennial wheat breeding lines were derived from a *T. elongatum*/Chinese Spring/Madsen population using a modified-bulk pedigree selection method. Genotypes were selected as single plants from a second year perennial bulk population grown in Pullman, WA from 2000 to 2002, and seed increased during the 2002–2003 and 2003–2004 field seasons. Selection was based on regrowth after harvest, winter survival after regrowth and subsequent seed set.

The 31 perennial genotypes were grown with two annual hard red winter wheat cultivars, 'Finley' and 'Bauermeister', at three rainfed locations in Washington State (Kahlotus, Ritzville and Pullman) in 2005/06 using a randomized complete block design with four replicates per location, as described in Murphy et al.[26]. Briefly, plots were 2.5 m long and 1.25 m wide and consisted of four rows at 30 cm spacing at Ritzville and Kahlotus and seven rows at 18 cm spacing at Pullman. Seeding rate was approximately 45 kg ha^{-1} at Ritzville and Kahlotus and 85 kg ha^{-1} at Pullman. Plots were fertilized with 46.0 kg ha^{-1} of N at Ritzville and Kahlotus. In Pullman, 100.8 kg ha^{-1} of N, 22.7 kg ha^{-1} of phosphate and 17.0 kg ha^{-1} of sulfur were incorporated into the soil within a week of planting. These fertilizer treatments reflect the locally prevalent application rates for annual wheat.

Plots were harvested at grain maturity with a Hege plot combine (Niederlassung, Germany) with stainless steel sieves and cleaned with a Hege seed cleaner with stainless steel sieves. A threshability index (TI) was estimated by dividing initial grain yield before cleaning by grain yield after a uniform cleaning process. The cleaning process removes seed with tenacious glumes that were still attached to the rachis while conserving only the threshed grain.

Analysis of variance in PROC GLM (SAS Institute, Cary, NC) was used to analyze data threshability and mineral concentration and to test for genotype × location interactions. Location and genotype were considered fixed.

Table 1. Grain yield (g plot^{-1}), regrowth (% regrowing plants plot^{-1}), threshability index (TI), thousand kernel weight (TKW) and mineral concentrations (μg g^{-1}) for calcium (Ca), copper (Cu), iron (Fe), magnesium (Mg), manganese (Mn), phosphorus (P) and zinc (Zn) reported for annual wheat cultivars (A) and perennial breeding lines (P) across three locations in Washington State (Kahlotus, Ritzville and Pullman) in 2005/06. Trait mean and standard error (SE) are shown at the bottom of the table.

Entry	Habit	Yield	Regrowth	TI	TKW	Ca	Cu	Fe	Mg	Mn	P	Zn
Finley	A	1318	0	0.98	32.5	368	3.93	33.4	1185	32.5	2885	20.3
Bauermeister	A	1207	0	0.96	34.5	392	3.86	38.1	1264	36.3	2986	21.6
P-0001	P	602	42.9	0.67	27.8	719	7.04	48.4	1612	48.5	4300	30.7
P-0002	P	613	45.8	0.68	28.7	679	6.46	47.9	1562	53.4	4068	31.6
P-0003	P	573	35.8	0.70	31.3	689	6.57	49.5	1585	51.4	4291	30.6
P-0004	P	476	33.8	0.71	28.3	777	6.71	51.8	1695	50.2	4755	33.9
P-0005	P	528	35.8	0.66	30.8	740	6.88	49.6	1642	52.9	4433	31.5
P-0006	P	539	63.8	0.65	29.1	728	6.28	47.6	1562	53.5	4172	34.8
P-0007	P	495	62.1	0.72	29.4	746	6.80	47.5	1573	54.1	4244	31.5
P-0008	P	597	59.2	0.63	30.7	723	6.67	52.6	1690	55.1	4523	34.1
P-0009	P	469	45.4	0.89	26.4	600	6.16	42.6	1422	46.6	3604	28.2
P-0010	P	494	35.0	0.78	26.7	633	6.02	45.5	1540	46.9	3858	28.9
P-0011	P	588	41.3	0.82	27.8	684	7.21	49.5	1644	53.7	4378	35.0
P-0012	P	475	48.8	0.75	29.4	604	6.23	46.7	1584	51.1	4166	33.0
P-0013	P	590	47.9	0.67	25.4	638	5.53	42.0	1448	40.0	3907	28.0
P-0014	P	634	22.5	0.67	28.0	654	6.43	46.9	1625	50.7	4204	30.5
P-0015	P	500	42.9	0.70	29.9	683	6.26	47.5	1621	51.8	4372	33.1
P-0016	P	603	41.7	0.65	27.2	690	6.38	45.3	1609	51.0	4205	31.0
P-0017	P	639	59.6	0.79	31.3	624	6.32	47.2	1605	50.2	4343	29.1
P-0018	P	472	75.4	0.79	30.3	729	6.13	45.8	1645	49.7	4446	27.6
P-0019	P	791	40.0	0.81	27.2	699	6.20	46.9	1622	49.8	4254	28.5
P-0020	P	517	38.3	0.84	26.8	725	6.45	47.9	1552	50.3	4198	30.4
P-0021	P	549	49.2	0.84	27.6	683	6.48	46.0	1565	49.8	4214	31.4
P-0022	P	457	51.3	0.70	30.3	656	6.48	46.1	1613	52.9	4228	30.4
P-0023	P	625	30.8	0.77	26.0	703	6.75	46.1	1607	54.8	4266	34.5
P-0024	P	452	52.5	0.79	27.8	718	6.44	46.5	1603	49.1	4223	31.4
P-0025	P	509	22.1	0.74	28.0	655	6.64	45.8	1601	53.3	4229	32.0
P-0026	P	523	25.4	0.87	28.7	642	6.12	42.1	1499	46.6	3993	30.4
P-0027	P	623	51.7	0.86	27.7	696	6.42	45.4	1618	50.3	4393	31.2
P-0028	P	520	49.6	0.83	26.1	613	6.66	44.8	1600	51.3	4113	32.4
P-0029	P	469	48.3	0.76	27.7	731	7.35	48.8	1690	55.9	4424	34.0
P-0030	P	578	41.7	0.72	26.2	716	6.68	47.8	1582	52.0	4117	31.2
P-0031	P	602	39.6	0.70	27.6	630	6.30	44.1	1496	50.4	3821	26.7
Mean (A)	A	1262	0	0.97	33.5	380	3.90	35.8	1224	34.4	2936	20.9
SE (A)	A	56	0	0.01	1.0	12	0.04	2.4	40	1.9	51	0.6
Mean (P)	P	552	44.5	0.75	28.3	684	6.49	46.8	1591	50.9	4218	31.2
SE (P)	P	13	2.2	0.01	0.3	8	0.06	0.4	11	0.6	40	0.4

Levene's test was used to test for homogeneity of variance across locations and normality was checked using the Shapiro–Wilk test in PROC Univariate (SAS Institute).

Fifteen soil subsamples were randomly collected to a depth of 30.5 cm and pooled for analysis at each location. Soil organic matter, pH, and available Cu, Fe, Mn, P and N were determined by the University of Idaho analytical soil testing laboratory.

Results

Grain mineral concentration

Micronutrient concentrations for Cu, Fe, Mn and Zn were 40, 24, 32 and 33% higher, respectively, in the perennial grain than in the annual grain (Table 1). Macronutrient concentration followed the same pattern, with Ca, Mg and P being 44, 23 and 30% higher, respectively, in the perennial lines (Table 1). Differences were found among genotypes for all minerals tested ($P < 0.001$).

Soil organic matter was 1.6, 2.0 and 2.6 for Kahlotus, Ritzville and Pullman, respectively. Soil pH was 5.5% for Kahlotus and Ritzville and 5.1% for Pullman. Cation exchange capacity was 14, 15 and 29 cmol(+) kg^{-1} respectively for Kahlotus, Ritzville and Pullman. Available soil mineral concentrations of Cu, Fe, Mn, N (nitrate+nitrite), N (ammonia) and P for each location are shown in Figure 1. Available potassium (K) was 650, 720 and 190 μg g^{-1} for Kahlotus, Ritzville and Pullman, respectively.

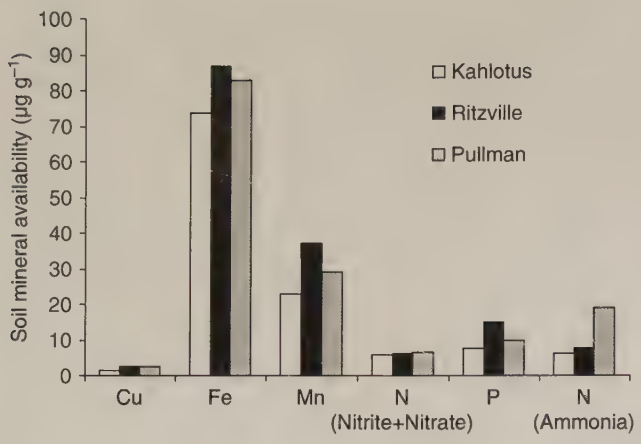

Figure 1. Soil bioavailability of copper (Cu), iron (Fe), manganese (Mn), nitrogen (N) with nitrites + nitrates, phosphorus and N in the form of ammonia at three locations (Kahlotus, Ritzville and Pullman) in Washington State.

Location had a significant effect on grain mineral concentration for all minerals tested. The perennial grain from Kahlotus had the highest level of all mineral nutrients except Mn (Fig. 2). Soil available Mn was accordingly lowest at this location (Fig. 1). All minerals were moderately to highly correlated with each other ($P < 0.05$) (Table 2).

Trait means across locations for each genotype are reported for grain yield, regrowth, TI, thousand kernel weight (TKW) and the seven minerals tested (Table 1). To estimate total mineral content of Cu, Fe and Zn per unit area for each genotype, we multiplied mineral concentration ($\mu g\,g^{-1}$) by grain yield per plot ($g\,plot^{-1}$), and divided by 1000. The annual cultivars had a mean of $4.92\,g\,plot^{-1}$ Cu (range = 4.65–5.18), $45.0\,g\,plot^{-1}$ Fe (range = 44.1–46.0), and $26.38\,g\,plot^{-1}$ Zn (range = 26.02–26.73). The perennials had a mean of $3.58\,g\,plot^{-1}$ Cu (range = 2.89–4.90), $25.9\,g\,plot^{-1}$ Fe (range 20.0–37.1) and $17.19\,g\,plot^{-1}$ Zn (range = 13.05–22.56).

Grain yield per plot was negatively correlated with grain mineral concentration for all minerals when the annual cultivars were included in the analysis (Table 2). When the correlation analysis included only the perennial breeding lines, no associations were found between grain yield and mineral concentration for any minerals (Table 2). When annuals were included in the analysis, TKW was negatively correlated with Ca, Cu and Zn; however, in the absence of the annual cultivars, TKW was positively associated with Mg, Mn and P (Table 2).

End-use quality

The perennial lines produced smaller and lighter kernels than the annual cultivars, resulting in decreased test weight (Tables 3 and 4). The perennial lines generally exhibited lower flour yield, loaf volume and mix time; greater whole wheat protein and flour protein content; and, similar ash content of flour compared to the annual cultivars (Table 3). Kernel hardness of the perennial lines was 47.8% lower than what is typically observed in hard wheat, while protein content of the perennial lines was 3.5–4.5% greater than the annual hard wheat cultivars (Table 4).

Whole wheat protein content ranged from 14.0 to 16.5% in Pullman and 15.2 to 17.6% in Ritzville for the perennial lines. For the annual cultivars, 'Bauermeister' had 11.6 and 12.7% whole wheat protein in Pullman and Ritzville, respectively, and 'Finley' had 12.4 and 12.7% whole wheat protein at the respective locations (Table 3). The annual hard red cultivars had greater kernel hardness, seed weight and seed size than the perennial lines (Table 4).

Threshability

The mean TI in the annual cultivars was 0.97. This was considerably higher than the perennial lines, which ranged from 0.63 to 0.89, with a mean of 0.75 (Table 1). A TI of 1.00 would indicate that all the glumes had been separated from the grain during harvest. A TI of 0.0 would indicate that the grain had very tenacious glumes and the seed would not separate from these glumes through standard mechanical harvest. A significant genotype × location interaction was found for TI ($P < 0.0001$). TI was positively

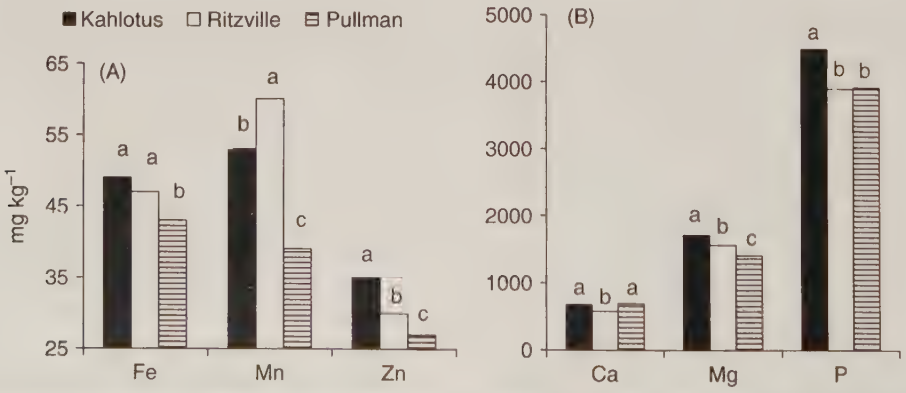

Figure 2. Effect of location (Kahlotus, Ritzville and Pullman) on micronutrient (A) and macronutrient (B) concentration ($mg\,kg^{-1}$ dry weight) in perennial grain grown in Washington State. Lower-case letters above the bars indicate significant differences ($P < 0.05$) among locations for each nutrient tested.

Table 2. Correlations between grain yield, regrowth after harvest, threshability index (TI), thousand kernel weight (TKW) and mineral concentrations of calcium (Ca), copper (Cu), iron (Fe), magnesium (Mg), manganese (Mn), phosphorus (P) and zinc (Zn) among annual and perennial breeding lines. Correlations below the leading diagonal include the annual wheat cultivars; correlations above the leading diagonal represent the perennial breeding lines only. $*P < 0.05$; $**P < 0.01$; $***P < 0.001$.

	Yield	Regrowth	TI	TKW	Ca	Cu	Fe	Mg	Mn	P	Zn
Yield		−0.18	−0.12	−0.14	−0.03	−0.07	0.04	0.05	−0.02	0.02	−0.16
Regrowth	−0.67***		−0.03	0.32	0.18	−0.10	0.08	0.10	0.08	0.16	−0.04
TI	0.52**	−0.43*		−0.34	−0.30	−0.09	−0.43*	−0.26	−0.23	−0.24	−0.18
TKW	0.52**	−0.24	0.16		0.18	0.12	0.47	0.39*	0.37*	0.48**	0.11
Ca	−0.80***	0.65***	−0.64***	−0.45**		0.49**	0.67***	0.59***	0.41*	0.70***	0.40*
Cu	−0.82***	0.56***	−0.56***	−0.50**	0.87***		0.64***	0.63***	0.73***	0.53**	0.61***
Fe	−0.68***	0.54**	−0.67***	−0.20	0.86***	0.85***		0.77***	0.63***	0.77***	0.58***
Mg	−0.75***	0.60***	−0.62***	−0.32	0.88***	0.89***	0.91***		0.65***	0.91***	0.56*
Mn	−0.74***	0.58***	−0.59***	−0.31	0.81***	0.91***	0.85***	0.88***		0.51**	0.66***
P	−0.75***	0.62***	−0.61***	−0.29	0.91***	0.86***	0.90***	0.97***	0.83***		0.55**
Zn	−0.74***	0.50**	−0.55***	−0.41*	0.79***	0.86***	0.82***	0.84***	0.87***	0.83***	

Table 3. End-use quality characteristics including test weight (Twt), single kernel hardness (SKHard), whole wheat protein (UWprt), flour yield (FYeld), flour ash (Fl Ash), flour protein (FProt), mixture absorption (MAbs), mix time (MTime) and loaf volume (LVol), measured for the two annual wheat cultivars ('Bauermeister' and 'Finley') and four perennial breeding lines in two locations (Pullman and Ritzville).

Variety	Location	Twt	SKHard	UWPrt	FYeld	Fl Ash	FProt	MAbs	MTime	LVol
Bauermeister	Pullman	60.2	70.3 ± 17.8	11.6	71.5	0.43	10.0	59.0	4.0	745
	Ritzville	60.1	75.9 ± 13.6	12.7	72.8	0.43	11.7	60.7	3.9	925
Finley	Pullman	62.7	71.2 ± 16.8	12.4	72.7	0.38	11.5	61.3	3.3	925
	Ritzville	62.9	74.3 ± 13.8	12.7	75.9	0.42	12.0	61.4	2.2	930
PF4R1-0009	Pullman	56.0	71.0 ± 20.2	14.0	62.1	0.46	12.3	57.9	3.7	755
	Ritzville	54.3	54.0 ± 17.0	15.2	61.8	0.48	13.6	60.3	2.8	820
PF4R1-0014	Pullman	56.3	50.1 ± 19.7	14.9	57.3	0.44	12.8	57.2	1.5	765
	Ritzville	55.4	38.6 ± 14.9	17.0	58.8	0.45	15.1	61.0	1.8	810
PF4R1-0019	Pullman	57.9	61.0 ± 18.1	14.8	58.9	0.39	12.2	56.3	2.2	775
	Ritzville	57.4	49.0 ± 16.0	16.2	59.2	0.40	13.9	58.3	1.2	795
PF4R1-0021	Pullman	54.6	45.0 ± 20.0	16.5	59.6	0.43	13.2	56.4	1.3	765
	Ritzville	55.7	35.1 ± 16.6	17.6	60.1	0.45	15.6	61.7	1.5	790
PF3R1-0030	Pullman	55.5	52.9 ± 19.6	15.2	59.8	0.42	13.3	56.4	1.7	705
	Ritzville	54.2	38.1 ± 18.6	17.3	62.0	0.45	15.5	60.4	1.4	760

Table 4. Quality characteristics, including test weight, percent whole wheat protein, single kernel hardness, thousand kernel seed weight (g) and single kernel seed size (mm), were compared between annual wheat cultivars and perennial breeding lines grown at three locations in Washington State (na = data unavailable for these tests in respective location).

Location	Growth habit	Test weight	Protein	Kernel hardness	Seed weight	Seed size
Kahlotus	Annual	na	14.5	70.9 ± 13.8	38.5 ± 7.5	2.55 ± 0.40
	Perennial	na	18.7	45.9 ± 17.3	25.4 ± 5.6	1.72 ± 0.34
Ritzville	Annual	61.5	12.7	75.1 ± 13.7	36.5 ± 7.9	2.50 ± 0.40
	Perennial	55.8	17.2	40.4 ± 16.2	26.4 ± 5.1	1.76 ± 0.33
Pullman	Annual	61.5	12	70.8 ± 17.3	na	na
	Perennial	56	15.5	47.8 ± 19.2	na	na

associated with yield and negatively correlated with regrowth when the annual cultivars were included in the analysis (Table 2). No phenotypic associations were found between either TI and yield or TI and regrowth when only the perennial lines were included in the analysis (Table 2).

Discussion

Grain mineral concentration

Cereal crops have the potential to provide a significant increase in the overall micronutrient availability for much of the world's population without access to diverse food crops[27]. The increased mineral nutrient concentration in the perennial grain is most likely derived from wheatgrass species *T. elongatum*. Accordingly, Uauy et al.[20] found increased Fe and Zn concentrations in synthetic hexaploids developed from tetraploid durum and the diploid wheat ancestor, *Aegilops tauchii*. The elevated concentrations of micronutrients in the perennial grain may be a result of improved scavenging ability of the larger roots of the perennial lines[28]; however, the total mineral content per unit area of cultivated land is significantly lower in the perennial grain than in the annual grain. This is predominantly due to the much higher grain yield in the annual cultivars.

Another reason for the enhanced micronutrient concentration in the perennial grain may be that the smaller grain size is directly related to the increased mineral concentration. This is known as the 'dilution effect'. The mineral concentration of the grain would decrease if a corresponding increase in grain size was due only to an increase in the endosperm and not the bran or germ, where the majority of the minerals are located. We found significant differences in TKW among the perennial lines (Table 1), and TKW was positively correlated with mineral concentration for Mg, Mn and P (Table 2). No relationship was found between TKW and the mineral concentrations of Ca, Cu, Fe or Zn among the perennial lines (Table 1). When the annual cultivars were included in the correlation analysis, however, TKW was negatively associated with Ca, Cu and Zn (Table 2).

This provides contradictory evidence regarding the dilution effect theory and is in part based on the issue of whether comparing the grain composition between annuals and perennials is an appropriate test of the dilution effect theory. For example, perennial and annual wheat should likely be considered two different crop species (much the same as wheat and triticale), as they differ in chromosome number and designation. Therefore, correlations among the perennial lines only (annuals excluded) may provide the most accurate account of the actual relationships between TKW and mineral concentration. Future research is needed to fully understand the roles that scavenging ability and the dilution effect play in achieving perennial grain with enhanced mineral nutrition and improved grain yield.

Grain mineral concentration is dependent to a great extent upon various soil properties, including soil organic matter, pH and the bioavailability of minerals in the soil[29–31]. Soils with a low pH have been shown to reduce uptake of the macronutrients Ca and Mg and to increase uptake of the micronutrients Zn, Mn and Fe[32]. The lack of a positive correlation between soil nutrient availability and grain nutrient concentration across all cultivars indicates that other environmental factors such as drought may have contributed to higher grain nutrient concentrations. In soybeans, plant stress induced by drought resulted in an increase in the accumulation of P, K, Ca, Mo, Mn, Cu and Zn, and may be an important response in drought stress tolerance[33]. The more drought-prone environments represented by Kahlotus and Ritzville generally showed higher levels of micronutrients in the grain than Pullman, the region with higher annual precipitation (Fig. 2).

End-use quality

Despite the much higher protein content compared to the annual cultivars, the perennial lines produced a smaller loaf volume of bread (Tables 3 and 4), indicating the weak protein strength and inferior gluten quality of these perennial wheat lines for baking bread. P-0021 had the highest whole wheat protein among the two annual cultivars and four perennial lines tested in Ritzville and Pullman (Table 3). Though the protein is not of bread baking quality, its enhanced concentration in the grain could have a significant dietary impact for human and livestock consumption. High protein livestock feed is important for many animals and perennial wheat could contribute to local production of high protein grain to complement mixed legume species in regions where soybeans are unable to grow, expensive to import or unavailable.

With the exception of one line (P-0009), most of the perennial lines showed similar water absorption and shorter mixing time in comparison to the annual cultivars. The relatively low flour yield found in the perennial lines was probably due to the low test weight and smaller kernels of the grain. These traits are important for baking quality and the variation among the perennial lines for these traits indicates the potential for genetic improvement.

Further improvements in grain characteristics, milling quality and protein strength of the perennial lines are needed before acceptable utilization as hard red hard wheat for baking is possible. The potential for perennial wheat in the soft white market class, however, is greater. Soft white wheat is the predominant market class in the Pacific Northwest, and is used for pastries, white Asian noodles, cookies, cereal flakes and flatbreads. In general, the quality of these products does not depend on protein strength and typical bread making characteristics like gluten quality and loaf volume. With this marketing option in mind, we have shifted a percentage of the perennial wheat breeding priorities to the selection of perennial lines with potential in the soft white market class.

Threshability and seed shattering

Thinopyrum species have tenacious glumes, a trait controlled by recessive mutations at the *Tg* loci, dominant modifying genes at the Q locus and additional modifying mutations at several other loci[34,35]. These tenacious glumes were transferred to a portion of the perennial progeny, making mechanical harvest less efficient. Though early domesticated wheat, with non-shattering, indehiscent spikes, have been found dating back to ~9250 years BP[36], the wild wheatgrass species we use in our perennial wheat breeding program have typically not been subject to artificial selection for either tenacious glumes or indehiscent spikes. Therefore, we anticipate selection for these traits to be of importance both during pre-breeding of wild species and selection of perennial wheat hybrids.

The TI range of 0.63–0.89 in the perennial lines indicates that the genes for threshability are segregating, and the population as a whole is tending to improve for this trait. Unlike selection for nutritional value and end-use quality traits, selection for increased threshability has potential for further improvement through the use of evolutionary breeding methods[37,38]. The significant genotype × location interaction for TI found in this study may be due to the environmental effect of abundant moisture at Pullman which reduced threshability.

We observed that plants with shorter spikes did not have the brittle rachis trait that we have found in many wild wheatgrass species and in perennial wheat hybrids with longer spikes (unpublished data). In the tetraploid emmer wheat, shattering is determined by the *Br* (brittle rachis) loci on chromosomes 3A and 3B[34,39]. In rice, Li et al.[40] showed that a single amino acid change is primarily responsible for the loss of shattering. The cultivated allele of the *sh4* (shattering4) gene confers both a non-shattering trait and allows for easy threshability of the grain. This suggests the potential for a rapid removal of the shattering trait from the perennial wheat genome. The brittle rachis trait, though possibly exploited in the Neolithic era bridging the hunter/gatherer era and the dawn of agriculture through ground gathering of shattered cereal spikelets[41], is a characteristic that does not conform to efficiencies needed for harvesting in modern agriculture.

Future Research in Perennial Wheat

Though the ability to transfer genes from perennial wild wheat species that confer the post-harvest regrowth trait is elegantly simple, there exist additional characteristics necessary for the successful establishment of perennial wheat[25]. These agronomic traits can vary by region and by agroecosystem and include disease resistance; drought, heat and cold tolerance; winter and/or summer dormancy; regrowth vigor and timing; and carbohydrate allocations in the root and crown[42–44].

This study focused on the post-harvest characteristics of mineral concentration, end-use quality and grain threshability. In addition to multiple agronomic traits, baking and milling quality and grain threshability must be improved before widespread adoption of perennial wheat by farmers, millers and bakers will occur. Though not a requirement for the successful development of a perennial wheat cultivar, increased grain mineral concentration is a reportedly beneficial trait currently found in perennial wheat breeding lines that should continue to be exploited and selected for in subsequent perennial wheat breeding evaluations.

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Browsing for conservation: Springtime forage value of midstory shrubs of degraded oak savannas in southern Wisconsin

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Abstract

Oak (*Quercus* spp.) savanna is a rare and dwindling ecosystem primarily due to the clearing of vast areas for agriculture and encroachment of woody midstory shrubs in the remnant areas. There is interest in introducing controlled grazing to re-open these ecologically sensitive semi-wooded areas. We report the forage quality and diet selection by Scottish Highland cattle (*Bos taurus* spp.), a breed recognized for their browsing behavior, of the most common shrubs in this ecosystem. Shrub species sampled included prickly ash (*Xanthoxylem americana* Mill), gooseberry (*Ribes missouriense* Nutt.), gray dogwood (*Cornus racemesa* L.), multiflora rose (*Rosa multiflora* Thunb. ex Murr.), black or red raspberry (*Rubus* spp.) and wild parsnip (*Pastinaca sativa* L). Leaf biomass was collected in June 2001 and 2002 and analyzed for forage quality. Animal observations showed that diet included a fairly even mixture of shrub leaves, grass and herbaceous forbs. Prickly ash and raspberry were most frequently browsed and had the highest crude protein (CP; 190 g kg^{-1}), while multiflora rose and gray dogwood, neither highly browsed upon, had the lowest levels of CP (120 g kg^{-1}). All shrubs had high *in-vitro* true digestibility, with prickly ash approaching 850 g kg^{-1} (as compared to 688 g kg^{-1} for mature alfalfa). The quality of the shrub layer in late spring is adequate to provide nutritional support for beef cattle as long as dry matter intake is not limited. Integrating shrubs into the rotation could expand the pasture base by providing feed at a time when cool-season pastures are typically quasi-dormant.

Key words: managed grazing, Scottish Highland cattle, browse, agro-ecology, brambles, scrub

Introduction

Historically, savanna communities have been an important component of the world's landscape, occurring on nearly every continent[1]. This ecosystem in the upper Midwest USA is characterized by widely scattered oak trees with an understory of herbaceous prairie grass, sedge and forb species[2]. It is estimated that 3 million ha of oak savanna existed in the upper Midwest prior to the arrival of Europeans, but less than 1% of this ecosystem remains today[3]. The loss of prairie and oak savanna can be attributed to two separate causes: agriculture/urban development and woody encroachment due to lack of proper grazing and/or fire management[4–7]. Without fire or moderate grazing, woody plant encroachment poses a major threat to grazing lands worldwide[8–11].

The reintroduction of fire or grazing has potential interest for savanna restoration as both are less labor intensive/expensive than hand-thinning or treating the shrubs with herbicides. Fire is not always successful at reducing dense shrubs, primarily due to lack of fuel beneath them[12], and it may subject farmers to serious liability issues. Managed (rotational) grazing with moderate stocking densities, however, has rarely been tested in restoring oak savanna structure. Hence, managed grazing may be a potential conservation management tool if the initial shrub quantity and quality can contribute to maintaining animal performance. Williams and Bronny suggest that using managed grazing has potential to clear out the overgrown understory of the oak savanna and restore its structure[13,14].

Uncultivated tree and shrub leaves are not commonly considered as cattle feed in the USA. Researchers have

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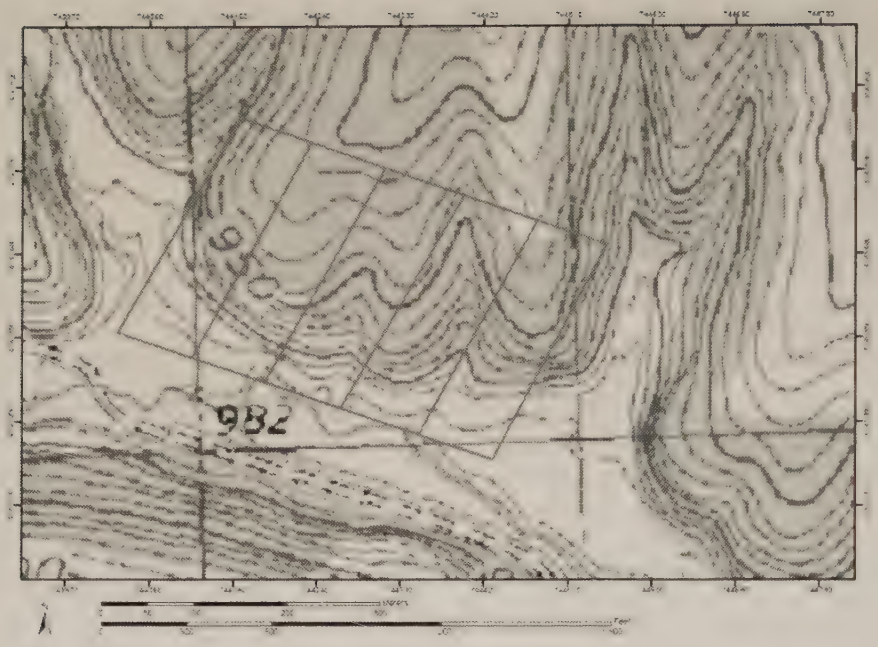

Figure 1. Topographical map with the experimental design laid over the top of one of the sites (YLWA) in the study. All three sites had similar steep slopes. The shaded areas represent wooded canopy from trees and shrubs while the white areas represent open areas covered with herbaceous grass and forbs.

generally found that browse makes up only a small part of cattle diet on the range[15], and although it can be of high quality[16,17], it often contains anti-nutritional elements such as tannins, phenolics or saponins[18–20], all which can reduce digestibility or cause metabolic problems. However, others report that herbivores are able to offset negative effects of these anti-quality factors and increase intake when given a diverse selection of plants to choose from[21].

In the USA, grazing has been tested to reduce shrub density and it may also serve as potential method to increase species diversity within the opened areas[22,23]. Observational information suggests that Scottish Highland cattle are good browsers, making them a possible management tool for opening rough habitat such as the overgrown shrub layer of degraded oak savanna. This cattle species is known for thriving in the rugged conditions of the Scottish Highlands[24,25]. Since most oak savanna exists on private land, the challenge is to determine whether cattle grazing behavior can be managed so that it will restore the savanna community structure with minimal impact on remnant native plant species and whether this process is of economic value to livestock producers. Three separate land managers interested in using grazing as a management tool wanted to open up the oak savanna on the edge of their grazing fields because they thought it would provide some forage, offer the animals some shelter in the hottest and coldest days, and be aesthetically pleasing. As part of a larger research project to measure the impact of grazing on the oak savanna vegetation[26] and its effect on animal performance[27], the objectives of this study were to: (1) measure shrub quality and variability; and (2) monitor behavior by Scottish Highland cattle when confronted with plant species common in degraded oak savannas. Our hypothesis is that if palatable, this shrub layer of the overgrown oak savanna could provide a supplemental feed source. This information on browse acceptability and feed value would help livestock owners and land managers to design feeding and supplementation strategies when expanding managed grazing acreage to include overgrown oak savanna remnants.

Methods

Site characterization

To compare the impact of grazing with no grazing on overgrown oak savanna, the study was established at three sites all within 20 km of each other, in the Driftless (unglaciated) region of southwestern Wisconsin. The three sites are Yellowstone Lake Wildlife Area (YLWA) in Lafayette County (43°02′N, 89°90′W), owned and managed by the Wisconsin Department of Natural Resources; and on two private farms: Prairie Oaks Farm (POF), also in Lafayette County (42°48′N, 89°55′W); and Craig-Is-Daru Farm (CIDF) in Iowa County (42°54′N, 89°52′W). POF and YLWA are typical (degraded) oak woodlands, dominated by bur and/or white oak (*Quercus macrocarpa* Michx. and *Quercus alba* L., respectively) with well-drained, shallow silt loam soils. CIDF is a (degraded) oak savanna with more shallow, sandy soil. These types of sites are often all that 'escaped the plow' due to their rough and steep terrain (Fig. 1).

The vegetation type was similar across the three study sites and is reflective of dry calcareous savanna as described by Will-Wolf and Stearns[28]. Specifically, each

site has remnant prairie patches including some native grasses such as little bluestem (*Schizachyrium scoparium* [Michx.] Nash), Indiangrass (*Sorghastrum nutans* L. Nash) and prairie dropseed (*Sporobolus heterolepis* [A. Gray]). Over all, 38 oak savanna indicator species were found in our baseline vegetation surveys[29]. However, these sites have been invaded by Eurasian temperate grasses such as smooth bromegrass (*Bromus inermis* Leyss) and Kentucky bluegrass (*Poa pratensis* L.) in the open areas. The most abundant shrub species, based on stem densities prior to the study, were red raspberry (*Rubus strigosus* Michx Foche), *blackberry (Rubus allegheniensis* Porter), and *black raspberry (Rubus occidentalis* L.)—collectively 30%; goose berry (*Ribes missouriense* Nutt.) 29%; hazelnut (*Corylus americana* Walter) 8%; prickly ash (*Zanthoxylum americanum* Mill) 8%; and gray dogwood (*Cornus racemosa* Lam.) 7%.

Experimental design

At each site, the experimental design was a randomized complete block with five replicates. This design was used in a concurrent study to measure the impact of cattle grazing on the vegetation, employing random transects and repeated measures on defined quadrats[26]. The trial was blocked according to topography and vegetation zones that included open grassland or prairie, shrub and tree-canopied zones. Each plot contained roughly two-thirds of canopied area (upslope) and one-third of open grassy area (downslope) to ensure adequate feed availability. Auto-filling water tanks were provided at the downslope end of each plot. The cattle were allowed to roam throughout the vegetation zones within a plot and were on a plot for 1 to 3 days per month.

Livestock and rotation schedule

All cattle for the study were sourced from the two collaborating farms, POF and CIDF, where cattle were typically managed on cool-season grass pasture adjacent to overgrown woodlands/savannas. Each year of the study, a unique group of six cow–calf pairs on each farm, or 12 yearling steers at YLWA, were rotationally grazed through the plots at a stocking rate of 15 animal units ha^{-1} $site^{-1}$. Plots at each site (0.4 ha each) were grazed for 1–3 days per month in 2–3 and 3–4 cycles per season on-farm and at YLWA, respectively, by a cohort of Scottish Highland cattle. In each block, the treatments consisted of grazing and an ungrazed check plot. The cattle were provided 1 day of grazing on open pasture between movements from block to block for a 25-day grazing cycle. If plots needed more time to recover after each rotation, the animals were grazed in an adjacent non-study area to maintain similar grazing situations. This eliminated the need for re-acclimation to the plots. To facilitate daily cattle management, yearling steers (approximately 230 kg) were used at YLWA, while cow–calf pairs (cow weight approximately 455 kg) were kept at the two on-farm sites. For this reason, comparison of behavior between cows and steers was not possible. For more detail on stocking rates and rotation schedules, see the concurrent research summaries[26,27].

Forage quality analysis

The most prevalent shrub species from each site were sampled in late June 2001 and 2002 for nutritional analysis. To simulate cattle browsing, leaf/petiole samples (and occasionally juvenile stems and canes from raspberry) were hand-plucked from the distal half of the younger branches within 2 m of the ground. The shrub species sampled at YLWA were prickly ash, gooseberry and gray dogwood. The species sampled from POF were prickly ash and multiflora rose (*Rosa multiflora* Thunb. ex Murr.), and at CIDF were red or black raspberry and wild parsnip (*Pastinaca sativa* L.). Although wild parsnip is not a shrub, it was included because of its phyto-phototoxicity notoriety among herbaceous plants, and cattle readily grazed it. Samples were analyzed for crude protein (CP) using the macro-Kjeldahl method to determine total nitrogen (N), then multiplying N by 6.25[30]. Neutral detergent fiber (NDF) analysis followed Goering and Van Soest[31] and Van Soest et al.[32] with methods modified by Mertens[33]. *In-vitro* true digestibility (IVTD) (stage 1) was used to measure forage digestibility (2001 samples only). The IVTD assay is similar to (apparent) *in-vitro* dry matter digestibility (stage 1) but goes one step further by refluxing the incubated residue in NDF solution to measure the bacterial component and digestible fiber of the cell wall[31,34,35]. To satisfy our curiosity, we compared IVTD between breeds using rumen fluid from Highland cattle as well as from Angus cattle (*Bos taurus* spp.), a common beef breed in the area. Rumen fluid was collected at a slaughterhouse in the area from one Angus and one Highland cow. Phosphorus (P) was analyzed as dry ash by spectrophotometer; potassium (K), calcium (Ca) and magnesium (Mg) were determined as dry ash by atomic absorption. Alfalfa was chosen as a reference species since it is often referred to as the 'queen' of forages, its quality is well documented, and we had a long history of data from our laboratory to test alongside our more atypical samples. Besides being compared to shrubs, the alfalfa reference material was tested alongside the shrub samples to provide quality control of the assays.

Monitoring cattle activity

Cattle observations were taken throughout the summer as the cattle moved across the grazing treatments and from block to block. Four trained observers using binoculars and stopwatches, and well-acquainted with the shrub species present at each site, monitored the cattle. Cattle behavior or activity (rubbing, trampling, standing, drinking and ruminating) and feeding choice (grass, forbs, shrub or tree) data were recorded throughout the season, with most observations from the six site-years consistently being recorded in mid-June and late August. The first set of observations each year was done after the animals had been on the plots for a

Table 1. Mean ($N = 10$) of quality parameters of various shrub species averaged across years, with SE in parentheses. Alfalfa reference samples shown for comparison.

Species	CP	NDF	IVTD
	----------g kg^{-1}----------		
Raspberry	166 (10)	404 (11)	674 (18)
Gray dogwood	107 (7)	246 (12)	791 (17)
Gooseberry	143 (5)	314 (12)	795 (19)
Multiflora rose	111 (4)	435 (12)	645 (19)
Prickly ash[1]	172 (8)	357 (9)	838 (10)
Wild parsnip	132 (9)	341 (9)	835 (15)
Mature alfalfa	168 (2)	475 (2)	688 (2)
Immature alfalfa	236 (2)	327 (1)	793 (5)

[1] Prickly ash was sampled at two sites so $N = 20$.
CP, crude protein; NDF, neutral detergent fiber; IVTD, *in-vitro* true digestibility.

Table 2. Mean ($N = 10$) of macro nutrient concentration of various shrub species averaged across years, with SE in parentheses. Alfalfa reference samples shown for comparison.[1]

Species	P	Ca	K	Mg
	----------g kg^{-1}----------			
Raspberry	2.5 (0.1)	7.8 (0.3)	18.0 (0.7)	4.8 (0.1)
Gray dogwood	1.8 (0.1)	17.3 (0.4)	8.7 (0.2)	3.7 (0.2)
Gooseberry	2.4 (0.1)	16.1 (0.5)	28.6 (0.2)	3.8 (0.2)
Multiflora rose	2.6 (0.1)	14.2 (0.5)	15.2 (0.5)	3.4 (0.1)
Prickly ash	2.8 (0.1)	16.6 (0.4)	22.3 (0.5)	3.2 (0.1)
Wild parsnip	4.9 (0.1)	12.2 (0.3)	28.5 (0.1)	6.1 (0.2)
Mature alfalfa	2.4	14.1	17.1	3.1
Immature alfalfa	3.5	18.0	22.1	2.6

[1] Data from National Research Council 1996[37].
P, phosphorus; Ca, calcium; K, potassium; Mg, magnesium.

week. To ensure the data represented cattle preferences, observations were collected in the early morning or late afternoon when it was relatively cool[36], and shortly after the animals were introduced to a new plot, when there was the greatest grazing selection. Each of six animals was observed in turn for a 5 min period. Observations were recorded every 15 s (20 total observation points) noting the location, behavior and, if eating, the feed choice of each animal. This was repeated four times per session, making the observations last about 2 h per day which allowed time for animals to move about and survey the plot. These data were expressed as a percent of the total number of observations. The 2 years, 3 research sites and 2–4 grazing periods per season resulted in a total of 1000 animal-monitoring periods and over 20,000 data points recorded. On-farm observations from the baby calves were excluded from the analysis since most of their nourishment came from their nursing mothers.

Statistical analyses

For the forage quality analysis reported in this paper, the mean of five spring plant samples (one per block) per year over 2 years is provided and standard error (SE) of the mean is shown for each species as a measure of within-species variability. A preliminary analysis of the cattle observations showed homogeneous errors for years, so a combined analysis is presented. Cattle observation data, however, are analyzed and discussed by site because of the variable shrub distribution between sites and different classes of grazing animals (cows and steers). To compare spring and summer cattle diet selection at each site, the chi-square test (with two degrees of freedom) was used with forbs, browse and grass.

Results and Discussion

Shrub feeding value

Forage quality of the shrubs, in terms of protein, digestibility and fiber, is characterized in Table 1. Although CP was highest for immature alfalfa, prickly ash and raspberry were comparable to that of mature alfalfa, and therefore good-quality forage for most classes of livestock (Table 1). Gray dogwood and multiflora rose ranked lowest in CP. Other researchers working with multiflora rose reported similar findings[16]. According to the National Research Council's Nutrient Requirements of Beef Cattle[37], growing or finishing cattle gaining over 0.9 kg day^{-1} generally need a concentration of 120–130 g kg^{-1} of CP (on a dry matter basis) in the feed they consume. It appears therefore that quite a few of these shrubs, in early summer, contain adequate protein content to meet this requirement if biomass availability and selection is not limiting. A note of caution, however, is that an analysis of anti-quality factors, such as lignin and tannins, was not conducted. However, the digestible fraction of the forage, measured as IVTD, was also high across species, averaging 763 g kg^{-1}, suggesting that the nutrients in these shrubs were not restricted by anti-quality traits. Furthermore, according to our animal performance data[27], protein did not appear to be limiting in the animals' diets. All except multiflora rose were comparable or higher than mature alfalfa in IVTD. Prickly ash was much higher in IVTD than the other shrubs, as was wild parsnip, ranking higher than the immature alfalfa. A higher proportion of stems or juvenile canes mixed in the sample might explain the lower IVTD for raspberry versus mostly leaves in the sample of the other shrub species. Likewise, NDF levels of the shrubs at these sites fell between the range of the high quality (immature) alfalfa and the mature alfalfa, with the exception of gray dogwood (Table 1). No difference was found in IVTD between the Angus and Highland breeds, suggesting that the rumen microbial species were similar between breeds.

Shrub macro mineral (P, Ca, K and Mg) concentrations

The macro-elements found in the shrub foliage were at levels similar to those found in alfalfa, but individual shrub species showed considerable variation (Table 2). Similar to

Table 3. Frequency of cattle in various activities and % of time eating five shrubs by site over 2 years, with SE in parentheses.

Site	YLWA	POF	CIDF	3-site mean
Class of cattle	Steers	Cows	Cows	
Total observations[1]	13,960	3080	3000	
% Eating	28	37	64	43 (11)
% Rub/trample	2	4	2	3 (1)
Grass (% of eating)	28	23	32	28 (3)
Forbs (% of eating)	51	36	38	42 (5)
Browse (% of eating)	21	41	30	31 (6)
Prickly ash (% of browse)	62	53	23	46 (12)
Rubus spp. (% of browse)	3	15	36	18 (10)
Gray dogwood (% of browse)	3	8	2	4 (2)
Multiflora rose (% of browse)	<1	1	17	6 (5)
Gooseberry (% of browse)	2	<1	0	1 (1)

[1] There were more observations at YLWA because there were more grazing cycles each year at this location.

the CP and NDF assays, gray dogwood was exceptionally low in P while the other shrubs were more comparable to alfalfa. Calcium levels across shrub species were similar to alfalfa, with the exception of wild parsnip and especially raspberry, which were low or very low in Ca: a reflection of the acidic, sandy soils on which these species were grown. Very low K levels were also found in gray dogwood while gooseberry had the highest K. Prickly ash ranked lowest of all shrubs in Mg. Wild parsnip was particularly high in Mg and tested more than two times higher than alfalfa and had higher levels than the $4.0\,g\,kg^{-1}$ level recommended per day by the NRC[37]. Overall, most species tested had adequate concentrations of the macro minerals for beef cattle.

Cattle observations

Of the total observations for each site, the cattle spent between 28 and 64% of the time eating, with about a third (31%) of that time browsing (Table 3). Shrub abundance likely influenced browsing choice as prickly ash was observed regularly in all the plots while gooseberry and gray dogwood were observed less frequently. These cattle ate leaves of most shrubs present but prickly ash was browsed most frequently at two of the sites (53–62% at POF and YLWA) while *Rubus* spp. were most often browsed at CIDF (36%). Gooseberry was the least browsed, likely due to its heavily thorned and small-leafed characteristics. It remains unclear why gray dogwood, an unthorned species, was rarely browsed. The remaining time was spent browsing miscellaneous tree species such as hickory (*Carya ovata*), elm (*Ulmus* spp.), cherry and plum (*Prunus* spp.) and hazelnut. While on the study, the cows essentially maintained their body weight and condition and their nursing calves and the steers had similar weight gains as the control group on pasture[27]. This supports the hypothesis that browse provided significant nutritional support. Hence, grazing shrub-infested savannas or woodlands could play a role in extending the cool-season pasture at a time of the season when this forage is typically quasi-dormant and lower in quality.

Table 4. Comparison of cattle spring and summer observational percentage-of-eating data by site over 2 years. Percentage of time eating browse, grass and forbs.

Site	Month	Browse	Grass	Forbs	*P* value[1]
		---------%---------			
YLWA (steers)	June	23.8	24.8	51.7	0.60
	August	21.9	25.1	52.9	
POF (cows)	June	36.1	29.5	33.8	<0.01
	August	60.6	0	39.3	
CIDF (cows)	June	30.6	36.0	33.3	<0.01
	August	27.4	21.8	50.8	

[1] Chi-square analysis was used to compare months.

Early and late seasonal observation data are presented in Table 4. With relatively abundant feed resources in June, we observed that the cows chose a diet fairly evenly distributed between grass, browse and forbs. However, by late August, the proportion of feedstuff in the cows' diets shifted from grass to either forbs or browse. The steers consumed a higher percentage of forbs in both June and August, with no shift in categories (Table 4); the herbaceous understory likely provided a higher energy dense diet for the growing steers. Ganskopp et al., working on rangeland, reported that Julian date and *in vitro* organic matter digestibility of the grasslands accounted for 98% of the variation in rates of use of shrubs by cattle[38]. Yet when we looked at the frequency data analysis for August, a time of year when cool-season grasses are typically lush and vegetative[39,40], the cattle were still consuming significant amounts of browse (22–61%). It is interesting to note that of over 250 observations at POF taken in the morning in late August, no grass was observed to be eaten. Another interesting observation was that wild parsnip, commonly encountered at CIDF, accounted for 14% of the forbs eaten there in June while no wild parsnip was observed to be eaten at any site in August.

In addition to eating the shrubs, cows further opened the canopy by occasionally trampling and rubbing on trees and shrubs (3% of observations). Similar behavior was observed in cattle in Idaho forestlands[36] and bison[41]. Further, in our study, cows would sometimes use their horns to knock down small trees (< 4 cm diameter) to reach the leaves. Similarly, Mitchell and Rodgers observed cattle trampling and pulling down branches of willow (*Salix* spp.) so the leaves could be consumed[36]. Results from the companion study on the ecological impact of grazing confirm that the animals did browse in the wooded area: Harrington and Kathol found that this grazing regime of 2 days per month for 3 or 4 cycles per year during the summer months resulted in significantly reduced density and height of *Rubus* spp., hazelnut and prickly ash[26].

One could expect that with the partial opening of the canopy from managed grazing and, if necessary, reseeding,

a more abundant and diverse savanna flora would develop (Tom and Kathy Brock, personal communication, 2004). This could result in a more open and attractive park-like appearance for the oak savanna perimeter of these pastures.

Conclusions

With the cessation of fire and grazing, succession of woody species has led to a degraded state of most of the remnant oak savanna, once an important ecosystem covering vast areas of pre-settlement Midwest USA. Managed grazing with the Scottish Highland cattle in these degraded savannas can effectively reduce the shrub layer while serving the dual purpose of providing feed and shelter to the livestock and creating a more aesthetically pleasing, open and more diverse savanna for humans and wildlife. The feed value of many of the understory shrubs are adequate to supplement a beef cattle diet and, when confronted with pasture and degraded oak savanna, Scottish Highland cattle will still spend significant amounts of time browsing. Our expectation is that with repeated managed grazing episodes, and perhaps some mechanical thinning, light would penetrate the understory, releasing the native vegetation associated with healthy savannas. Further research is necessary to evaluate differences between cattle breeds on their browsing ability and behavior when confronted with an overgrown thicket, and to test the quality and acceptability of additional species such as the invasive buckthorn (*Frangula alnus*) or garlic mustard (*Alliaria petiolata*). Furthermore, the impact of grazing degraded oak savannas and woodlands on biodiversity, such as insects, grassland birds and small mammal populations, would be important information to acquire.

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Soilless cultivation for high-quality vegetables with biogas manure in China: Feasibility and benefit analysis

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Abstract

Vegetables, the indispensable staple produce providing humans with many beneficial substances, are readily contaminated by nitrate, heavy metals and pesticides during conventional cultivation. In particular, off-season vegetables grown in protected systems with low light intensity do tend to accumulate more nitrate in tissues due to excess N fertilization driven by farmers' desire for high yields. Over-the-limit accumulation of the harmful substances in vegetables constitutes a serious hazard to human health globally. Soilless cultivation, currently a fraction of vegetable cultivation in China, is a promising cultivation method to decrease the accumulation of harmful substances through nutrient solution regulation and environmental factor control. However, conventional inorganic nutrient solutions present few quality benefits besides plant nutrition for the widely acknowledged formulations. Currently, high-quality vegetables are urgently desired by humans globally, but they are difficult to grow for lack of an effective and practical cultivation method to lower the accumulation of harmful substances and to improve nutritional quality simultaneously. Although some attempts have been made, few commercial formulations have been applied in practice. Biogas manure (biogas slurry and biogas dregs) is a by-product of biogas production. It has been shown to be a good fertilizer with abundant nutrients, amino acids and bioactive substances. In China, as a product of the recycling process of agricultural wastes, biogas manure is an ever-growing resource due to the rapid development of biogas projects. Therefore, the need to utilize biogas manure is an urgent issue that relates both to environment protection and nutrient resources utilization. In this paper, the updated research results on yield and the quality effects of vegetables cultivated with biogas dregs and the solutions modified from biogas slurry in China are summarized, highlighting the feasibility and benefits of biogas manure in high-quality vegetable production. It is concluded that biogas manure is an effective nutrient source for high-quality vegetable production based on its synergistic effects and effectiveness in yield and quality improvement (particularly depression effects on nitrate accumulation), and stress resistance. However, deliberate component regulations need to be developed for better yield and quality of vegetables under soilless cultivation due to the large variability of components of biogas manure caused by various combinations of fermentative materials.

Key words: high-quality vegetables, biogas manure, nitrate, quality, feasibility

Introduction

Vegetables, as the basal source of essential substances such as vitamins, beneficial active ingredients, cellulose, amino acids and mineral elements, are always required to contain as much of these essential nutrients to meet dietary requirements of humans, without over-the-limit of contaminants such as nitrate, nitrite, heavy metals and pesticide residues. However, vegetables are readily contaminated by nitrate and heavy metals during conventional cultivation with mass input of manure and fertilizer. In particular, off-season vegetables cultivated in protected systems with low light intensity do tend to accumulate more nitrates in tissues due to excess N fertilization driven by farmers' desire for high yields[1]. Over-the-limit accumulation of the harmful substances in vegetables constitutes a serious global hazard to human health. Moreover, since vegetables are usually harvested at vegetative growth stages, and the edible parts

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(young stems and leaves) can accumulate relatively large amounts of nitrate, vegetables have been found to be the major source of nitrate intake by humans, accounting for more than 80% of the total[2]. In addition, frequent application of pesticides easily leads to accumulation of residues during the short growth period and lack of time for them to be fully degraded. For soil cultivation, together with the inputs of large amounts of nitrogen, phosphates and organic fertilizer, substantial amounts of nitrate and heavy metals are accumulated in soil and are subsequently absorbed and accumulated in vegetables[3–5]. Currently, in China and the whole world, over-the-limit levels of nitrate, heavy metals and pesticide residues in vegetables are posing a serious threat to human health[3–7]. Globally, a serious situation was found in nitrate and heavy metal pollution in vegetables in terms of the limits issued by the different countries. In addition, apart from hygienic quality, nutritional quality of vegetables is another important issue that is of wide concern to humans. Nowadays, the quality of both the hygiene and nutrition of vegetables should be considered in the assessment of the quality of vegetables grown by various methods with respect to human health.

With the rapid development of livestock production in China, the amount of livestock wastes being generated is increasing, which gives rise to serious agricultural non-point source pollution when the waste is improperly disposed[8]. In China, biogas production is a good method for processing agricultural wastes[9,10]. This process can maximize the utilization of biomass energy, minimize the emission of greenhouse gases and loss of N and P compounds through anaerobic fermentation. Biogas is a very important renewable energy that is used for cooking and lighting in China[11]. Therefore, the Chinese government has encouraged the establishment of biogas projects to process the biological wastes. However, besides biogas, a great deal of by-products including biogas slurry and biogas dregs is also produced during the fermentation process. Thus, a new environmental issue has arisen. The discharge of biogas manure directly into the environment may result in serious problems, like eutrophication of surface water, over-the-limit levels of nitrate in groundwater, soil salinization, etc. Currently, improper application or disposal of biogas manure is severe in China since there are no acceptable methods for its use in agriculture with high economic benefits. However, the so-called pollutants in biogas manure, N and P, in turn, are the leading nutrients for crop production. Currently, in China, biogas manure is being explored for a win–win safe use as fertilizer for crop cultivation, particular high-quality off-season vegetable production in protected systems. Based on the constituent characteristic of biogas manure, many attempts have been made to investigate the feasibility and benefits of biogas manure on vegetables, crops and fruit trees. It is obvious that recycling of biogas manure in agriculture is multi-beneficial for both agricultural production and environmental protection. The research on biogas manure application in soilless vegetable production is reviewed here, highlighting the feasibility and benefits of biogas manure in high-quality vegetable production.

Application Methods of Biogas Manure in Agriculture in China

It has been well documented that biogas manure can be applied to agriculture as a fertilizer, protector, regulator and feed additive for pigs, functioning based on its diverse constitutes including abundant nutrients, amino acids, bioactive substances, etc. It has been proven that biogas manure could be generally applied in three ways. First, biogas slurry, as fertilizer, can support crop growth[9,12]. In general, biogas manure provides almost all mineral nutrients for crop growth and development in quantities close to the crop requirements[13]. Second, biogas slurry can protect crops from stress. In biogas manure, bioactive substances, such as hormones, nucleic acids, monosaccharides, free amino acids, vitamins, unsaturated fatty acids, proline, linoleic acid and fulvic acid, and so on, play important roles in protecting crops from biotic and abiotic stress[14]. It has been widely acknowledged that, for instance, gibberellins stimulate seed germination and plant growth[15], and vitamins promote disease resistance[16]. Third, biogas slurry makes a good animal feed, providing important nutritional substances, such as carbohydrates, amino acids, microelements, hormones and crude proteins[17,18]. In brief, biogas manure contains considerable amounts of plant nutrients and its use as a nutrient source may offer a promising win–win opportunity to improve crop production and, at the same time, to prevent adverse environmental impacts of biogas manure disposal. However, some urgent issues in the utilization of biogas slurry in crop production in China should be solved. First, there are no effective and practical methods to utilize biogas manure. Therefore, novel methods with acceptable economic benefits need to be developed. Second, the application of excessive amounts in agro-ecosystems often leads to adverse effects on soil quality, including the lack of holding capacity in different kinds of soils. Thus, investigations are needed to optimize these crucial parameters. Third, there are still some puzzles on how biogas slurry affects the growth and physiological status of crops, which need further investigations. In comparison with biogas slurry, biogas dregs are even less utilized in agriculture. Taking the feasibility, benefits and significance of the possible utilization methods in China into consideration, soilless cultivation of vegetables is a good way to use biogas manure with the advantage of optimally utilizing the functional constituents of biogas slurry. Most important, many functional substances such as amino acids can improve the nutritional and hygiene quality of vegetables to some extent, which must be controlled within the limits of the issued standards[19].

High-quality Vegetable Cultivation in China: Current Problems

Vegetables are high-value produce in China, particular during the out-of-season period. High economic benefits of vegetable cultivation under protected conditions has encouraged more and more farmers to establish solar greenhouses to produce vegetables in winter and spring. Currently, China ranks first in the world in the cultivation of protected vegetables, with up to 3.0 million hm^2 under cover in 2007[20]. However, vegetable quality (nutritional quality and hygienic quality) has declined in the past decade due to the increased fertilization level[3–5]. In 2007, the total input of fertilizers reached 51 million tons in China, and average nitrogen, particularly high in protected vegetables, has climbed up to 450 kg/hm^2[21]. High levels of nitrogen (urea and NH_4^+-N included) in soil will transform into nitrate, which is unavoidably absorbed and is substantially accumulated in vegetables to a harmful level for human health. In soilless cultivation, nitrate accumulation in vegetables is also unavoidable since nitrate/nitrogen has to be added into the nutrient solution or substrate to avoid ammonia toxicity and to balance medium pH. Moreover, low light intensity in protected systems could substantially increase nitrate accumulation in vegetables[22]. Previous data indicated that nitrate as well as heavy metals in vegetables had reached a serious level according to some international or domestic standards[3–5]. In China, improving the quality of vegetables is urgently needed.

The definition of high-quality vegetables is: vegetables that do not contain over-the-limit harmful substances (nitrate, nitrite, heavy metals and pesticides) and which do not have negative effects on human health after ingestion. For soil culture, at present, it is hard to produce high-quality vegetables in the field with the high-level nitrate, heavy metal and pesticide accumulation in soils combined with continued annual heavy input. Therefore, an alternative method to produce high-quality vegetables is urgently needed. To sum up, in high-quality vegetable production, inputs of fertilizers and pesticides should be lowered in order to ensure no over-the-limit accumulation of harmful substances in vegetables. Along with yield, hygienic quality assurance and the nutritional quality of vegetables should be improved as much as possible. In modern horticulture the trend is increasingly toward more soilless cultivation, which has advantages over soil-based production (e.g. decreasing succession cropping obstacles, avoiding ground water pollution and less soilborne diseases). Currently, excessive accumulation in vegetables of nitrate, heavy metals and pesticides are the major problems existing in high-quality vegetable production in soilless cultivation.

Nitrate is naturally present in all vegetables. Green, leafy vegetables, e.g. lettuce and spinach, contain relatively high concentrations. Nitrate and nitrite contamination in vegetables is produced mainly by overuse of chemical fertilizers besides low light intensity in protected systems. High intake of nitrate can transform into nitrite and then react with various proteins in the digestive system. The product, nitrosamine, is mutagenic and carcinogenic[23]. In order to eliminate the above hazards, obligatory standards have been released by many countries and international organizations. For example, the World Health Organization (WHO) and Food and Agriculture Organization (FAO) established the acceptable daily intakes (ADI) for nitrate and nitrite in 1973, 3.65 and 0.13 mg/kg (body weight), respectively. That is, for a 60 kg person, he/she is allowed to eat less than 0.5 kg fresh vegetables in which nitrate concentration is over 438 mg/kg. The European Commission has set maximum limits for levels of nitrate in lettuce and spinach[24]. In China, the content of heavy metals, nitrite and nitrate in the tissues of high-quality vegetables' is assessed under the limits of the GB-18406-2001 standard. For example, nitrite content in vegetables is less than or equal to 4.0 mg/kg (fresh weight), while the limits for nitrate content are 600 mg/kg for fruit vegetables, 1200 mg/kg (fresh weight) for stem and root vegetables and 3000 mg/kg (fresh weight) for leafy vegetables. In the newer standard, GB-19338-2003, the above limits are changed to 440, 1200 and 2500 mg/kg (fresh weight), respectively. The contents of five heavy metals and more than 40 pesticides were limited in the above standard. According to these tolerance limits, nitrate contamination in vegetables in most regions of China is a serious problem[3]. In general, nitrate content is the principal harmful substance that is difficult to control due to the large quantity of vegetables needed and their biological characteristics for easy accumulation of nitrates. Therefore, to develop effective methods to control nitrate accumulation in vegetables is an urgent issue in China and the whole world.

High-quality Vegetable Cultivation with Biogas Manure: Feasibility Analysis

As a staple food worldwide, vegetables need special assurances on quality (nutritional quality and hygienic quality). Excessive nitrate, heavy metal and pesticide contents in vegetables are basic problems. Application of biogas manure in vegetable production could specifically help solve these tough problems. It has been verified that the application of biogas manure improves yield, nutritional quality and stress resistance. Furthermore, biogas manure has a particular role in decreasing nitrate and heavy metal contents in vegetables. Based on the above functions of biogas manure, vegetables cultivated with biogas manure using appropriate management measures (e.g. quality control and composition regulation of biogas manure) will not exceed the tolerance limits for nitrate, heavy metals and pesticide residues.

The raw materials for biogas production, animal wastes, are mainly transformed from feeds, which are mostly plant-derived. Biogas slurry therefore consists of similar kinds and ratios of mineral elements as the physiological requirements of crops since few elements are lost during

anaerobic fermentation. Biogas slurry contains abundant N (0.03–0.08%), P (0.02–0.07%), K (0.05–1.4%), as well as Mg (97 mg/l), S (14.3 mg/l), Cu (36.8 μg/l), Fe (1.4 μg/l), Mo (4.2 μg/l), etc. In addition, the beneficial elements Ca, Cl, Na, Si, Co, Sr, Li, F and Ba are also contained in biogas slurry[13]. Biogas slurry has a higher nutrient content than compost, and recovery rates for N, P and K exceed 90% after digestion[25]. Therefore, biogas slurry is a complete nutrient solution that basically meets the needs of vegetable growth. Similarly, dry dregs also contain abundant nutrient substances including organic matter (36–50%), humic substance (10.1–24.6%), nitrogen (0.78–1.61%), P (0.39–0.71%, P_2O_5) and potassium (0.61–1.3, K_2O)[13].

Partial replacement of nitrate in nutrient solution with amino acids at 20 and 30% could significantly decrease nitrate accumulation in vegetables[26–30]. However, this is hard to apply in practice due to the high cost of amino acids. More than 15 acid amides and amino acids can be found in biogas slurry in amounts of 500 mg/l.[13,31] Therefore, biogas slurry is a suitable alternative to solve this issue. Moreover, in biogas slurry, mixed amino acids are presented. Some authors have proven that mixed amino acids are more efficient in lowering nitrate content in vegetables[27,30,31]. Of course, based on the complex components of biogas slurry, the effects of biogas slurry on nitrate accumulation in vegetables cannot be attributed only to the presence of amino acids; there are still some unknown mechanisms to be revealed. Shi et al.[32] suggested that biogas slurry had dual functions as a bio-fertilizer and bio-pesticide, without resistance evolution and environmental pollution. Furthermore, over 20 compounds of 120 substances in biogas slurry have the functions of anti-disease and insect prevention[33]. As mentioned above, some constituents of biogas slurry could increase the resistance to abiotic stress, such as drought, chilling and so on. All the above functions are helpful in vegetable cultivation to ensure that the contents of nitrate and pesticides are under the limit. As to heavy metal content, there is a lack of sufficient data to draw a conclusion; however, the proper selection of fermentative materials could easily help control the content of heavy metals in biogas manure. In addition, biogas manure is pathogen- and vermin egg-free after the long-term fermentation process[13]. Based on the above-mentioned ingredient analysis, it is concluded that biogas slurry is a feasible nutrient solution for soilless cultivation of high-quality vegetables.

High-quality Vegetable Cultivation with Biogas Manure: Benefit Analysis

In China, the studies on effects of biogas slurry on vegetable nitrate content, yield and quality have been conducted for more than two decades. To date, more than ten vegetable species, including lettuce, Chinese cabbage, rape, Malabar spinach, tomato, cucumber, garlic, green pepper, *Ipmoea aquatica* Forsk., bitter gourd and *Gynura bicoloar*, etc., have been tested and successfully grown in soil and soilless conditions supplied with biogas manure showing substantial benefits. Among the tested vegetable species, lettuce is the most common species studied. In terms of yield and quality, it is well reported that biogas manure was efficient in promoting yield and quality of vegetables. However, no comprehensive review had been published to summarize the current status of this issue in China. In this paper, studies have been integrated to provide a reference for researchers worldwide.

Yield

As early as 1985, Zhu[34] found that the application of biogas slurry could increase the yield of Chinese cabbage. In the 2000s, more than 20 studies have been conducted focusing on the application effectiveness of biogas manure in the cultivation of vegetables. Among the previous investigations, the majority of results were obtained in pot experiments and field experiments by the soil cultivation method. The majority of results showed that biogas manure application will enhance the yield of vegetables, such as celery[35], Chinese cabbage[34], pakchoi[36], lettuce[19,37,38], green pepper[39], mustard[40], *Ipmoea aquatica* Forsk.[41] and mushroom[42]. Recently, some studies have been conducted successfully under soilless conditions. These have confirmed that lettuce[19,43,44], Malabar spinach[45], *Gynura*, *Gynura divaricata* and Purple leaf lettuce[12], cucumber[46,47], pepper[39] and *Ipmoea aquatica* Forsk.[41] can be cultivated successfully with a modified biogas slurry solution.

Nutritional quality

The content of soluble sugar, vitamin C, acidity and amino acids of vegetables are the main indices that have been examined in previous studies. In summary, there are inconsistent effects of biogas slurry on vitamin C and the soluble sugar content of vegetables. Some reports showed that vitamin C and soluble sugar in pakchoi[36], lettuce[43] and cucumber[46] were increased. However, in contrast, Xu et al.[37,38] found that soluble sugar and vitamin C of lettuce cultivated with biogas slurry were decreased. Similar results were presented in mustard[40]. In addition, Zhou et al.[39] found no influence of biogas slurry on vitamin C and soluble sugar content in pepper, but the ratio of sugar to acid was increased. To sum up, current data about the effects of biogas manure on nutritional quality are confused, which may be caused by discrepancies in experimental materials and various experimental conditions. More investigations should therefore be conducted to clarify the effects on quality and their mechanisms.

The nitrate content is an important index used in almost all related studies to determine the nutrient quality of vegetables. Almost all results showed consistently that the nitrate content of vegetables was decreased significantly after cultivation with biogas manure, in both soil and soilless cultivation. The vegetable species reported include Malabar spinach[43], lettuce[19,37,38,42], rape[18,31], cucumber[29]

Table 1. Results of previous studies on the effects of biogas manure on yield and quality of vegetables grown soilless.

Vegetable species	Yield effects or feasibility	Nitrate content	Nutritional indices	References
Malabar spinach	Decreased	481 mg/kg, decreased by 67.4%	Soluble sugar and Vc were reduced	Li et al.[45]
Gynura, *Gynura divaricata* and Purple leaf lettuce	Feasible	–	–	Ning et al.[12]
Lettuce	Increased	–	–	Yang[44]
Cucumber	Feasible	–	–	Yuan[53]
Pepper	Increased	16 mg/kg, decreased by 72%	Reduced fruit acidity but did not affect V_C content	Zhou et al.[39]
Lettuce	Increased	59 mg/kg, decreased by 88%	Reduced sugar, total sugar and Vc increased by 74, 73 and 106% respectively	Su et al.[43]
Lettuce	Increased	209 mg/kg, decreased by 77%	–	Liu et al.[19]
Bailin mushroom	Increased	–	–	Ji et al.[42]
Tomato	Increased	–	Enhanced the content of soluble sugar and protein in fruit	Lu et al.[54]
Ipmoea aquatica Forsk.	Decreased	244 mg/kg, decreased by 75%	Vc increased by 38%	Lin et al.[41]

Vc, vitamin C.

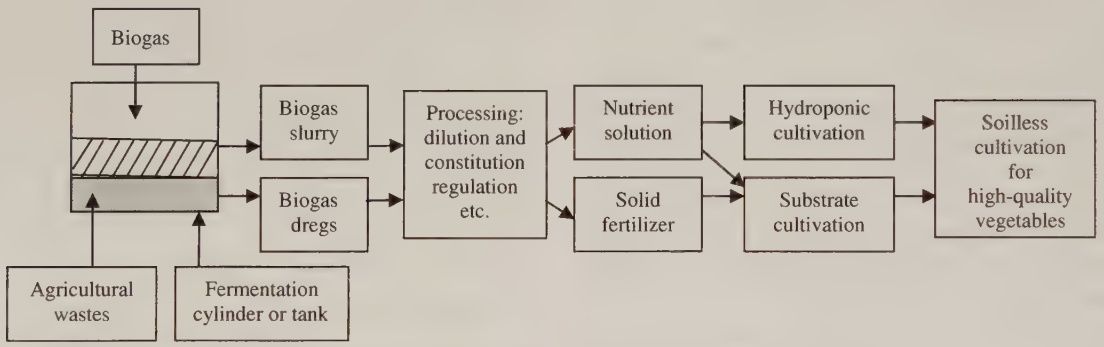

Figure 1. Process flow of soilless cultivation with modified biogas manure, and regulation measures.

and mustard[40]. Also, a study showed that the content of Hg, Cr and Cd in lettuce was decreased with increasing proportion and amount of biogas manure used in soil cultivation[48]. Light intensity has a strong influence on nitrate accumulation in vegetables[23]. Nitrate can accumulate to dangerous levels under low light conditions, when nitrate reductase is inactive[49]. China is the world's largest producer of vegetables grown in protected systems[20]; thus improving the light conditions in off-season production of vegetables is an effective method to depress nitrate accumulation. Some hydroponic lettuce producers address the problem by giving their plants N-reduced nutrient solution or supplemental light prior to harvest[50,51]. Future research should integrate these methods together, investigate the combined effects, and optimize the efficiency of lowering the nitrate level in vegetables.

Disease resistance

Many of the beneficial effects on disease resistance of biogas manures, particularly biogas slurry, have previously been demonstrated. Recently, some bio-pesticides based on biogas slurry have been investigated[33]. It is estimated that the application of biogas manure will reduce by over 20% the dosage of chemical fertilizers and pesticides, and lower by 1% the rate of pesticide residues (China National Plan on Rural Biogas Construction Projects of 2006–2010). However, the mechanisms of action of biogas manures still need to be investigated carefully. Three mechanisms of action have been revealed: (1) NH_4^+, acetic acid, butyric acid, propionic acid, gibberellin and indoleacetic acid in biogas slurry are effective anti-disease substances that can inhibit the occurrence of diseases and insects; (2) vitamins and amino acids increase the ability of crops to resist diseases; and (3) volatilization of methane and ethylene gas will help keep off pathogenic bacteria and insects. Jothi et al.[52] found that tomato plants amended with biogas slurry had more vegetative growth and tended to flower and fruit much earlier when compared with the control. The nematode population in the soil decreased, thus decreasing the severity of nematode attack.

Some authors have suggested biogas manure as a feasible nutrient resource for high-quality vegetable production under soilless conditions, with the advantages of high yield

and good quality[12,43]. To sum up, biogas slurry can be used as a nutrient solution, while biogas dregs can serve dual functions as solid manure and cultivation substrate for vegetable cultivation. Yuan[53] found that the mixed substrate of rough river sand and sawdust (1 : 1) was best for soilless culture of cucumber with 50% biogas slurry (water/biogas slurry, 1 : 1). In general, the original biogas slurry with high electrical conductivity (EC) was not suitable for vegetable cultivation[44]. Some authors suggested that appropriate adjustments before use (e.g. dilution and the addition of fertilizer) will enhance the cultivation effectiveness. Liu et al.[19] found that biogas slurry could grow higher biomass lettuce after being diluted at 1 : 4 or 1 : 5 (v/v, biogas slurry/water). The yields of Malabar spinach in the treatment supplied with 50% biogas slurry were the highest[43]. Ning et al.[12] confirmed that it is feasible to utilize the biogas digested fluid as the nutrient solution in soilless plantings of Gynura (*Gynura divaricata*) and Purple leaf lettuce, with the dilution ratio of 1 : 4 of biogas digested fluid. Liu et al.[19] found that biogas slurry (1 : 5 dilution) could significantly decrease nitrate content in lettuce, and the added amino acids in biogas slurry would bestow other benefits. Biogas slurry was used as nutrient solution for soilless tomato cultivation, and it improved tomato yield and quality. Also Lu et al.[54] found that biogas slurry diluted to a ratio of 1 : 8 (v/v) was the most suitable for tomato growth in the experiment. The relevant literature dealing with the soilless cultivation of vegetables and its efficiency is summarized in Table 1.

Research Prospects

Utilization of biogas manure is a key issue for sustainable development of the biogas industry and rural eco-environment. Based on the present data, chemical fertilizer can be entirely substituted by biogas manure in soilless culture[55]. Both yield and quality of vegetables cultured by nutrient solutions modified from biogas slurry are usually improved. Furthermore, nitrate accumulation in vegetables is largely lowered, heavy metals and pesticide residues in vegetables can also be controlled. In summary, biogas slurry, after proper adjustment, is a feasible nutrient solution for high-quality vegetable production. However, ingredients of biogas manure differ with species, ratios and amount of materials for anaerobic fermentation[54]. Furthermore, they could also be modified by local agronomic measures such as fertilization, spraying pesticide, soil type and climate conditions. Although ingredients of biogas manure are variable, they can be adjusted through adding mineral elements to realize the optimal components for vegetable growth. Thus, biogas slurry can be looked on as an adjustable liquid fertilizer. Many authors have suggested that biogas slurry was an excellent organic fertilizer, which could be used in soilless cultivation of vegetables[19,12,55]. Investigations are needed to develop regulation techniques aiming at optimizing the composition of biogas manure to increase the cultivation efficacy during pre-production, production and post-production of biogas. In addition, nutrient amendment strategies for biogas manure should be designed to balance the nutrient ratio to cater for vegetable uptake requirements[12]. All in all, three kinds of regulation measures can be conducted during the production of biogas manure for vegetable soilless cultivation (Fig. 1), including material constituents, fermentative conditions and constitutive modification of biogas manure.

China currently has a large number of methane tanks run by farmers, large-scale plants of livestock production and industrial enterprises. There were 18 million methane tanks used by farmers at the end of 2005 in rural areas, and 1500 were run by large-scale plants of livestock production and industrial enterprises. As designed in The Eleventh Five-year Plan of Renewable Energy Development of China, China will possess 40 million biogas farmer–users, and 4700 biogas projects for large-scale plants of livestock breeding and 1600 biogas projects for treatment of organic wastes from industry by 2010. It appears that a large quantity of biogas manure will be produced in the future. On the basis of eco-economy, biogas slurry and biogas residues re-utilization is a substantially beneficial action. The main advantages of high-quality vegetable cultivation with the modified biogas slurry, as a feasible alternative to the traditional inorganic nutrient solution, are to reduce the negative effects of environmentally toxic substances and improve the quality of vegetables. In China, it is highly feasible to combine the two developmental tendencies of increased biogas production and the need for high-quality vegetables. When this combination is applied widely in China, it is believed that non-point pollution will be reduced, even considering the ever-growing intensive livestock farming. To sum up, it is concluded that the application of biogas slurry in vegetable cultivation is a feasible pathway to agricultural production and environmental protection. China is the world's largest producer and consumer of vegetables in protected facilities; both the government and scientists should pay more attention to soilless production of high-quality off-season vegetables because, after all, public concern about vegetable quality and health is growing.

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Biological indicators of soil quality in organic farming systems

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Abstract

The health of the soil, recognized by its active role in the linked processes of decomposition and nutrient supply, is considered as the foundation of agriculture by the organic farming movement. Nutrient management in organically managed soils is fundamentally different from that of conventional agricultural systems. Crop rotations are designed with regard to maintenance of fertility with a focus on nutrient recycling. Where nutrients are added to the system, inputs are in organic and/or non-synthetic fertilizer sources that are mostly slow release in nature. Hence a greater reliance is placed on soil chemical and biological processes to release nutrients in plant-available forms. In this respect, nutrient availability in organically farmed soils is more dependent upon soil processes than is the case in conventional agriculture. The development and use of biological indicators of soil quality may therefore be more important in organic (and other low input) farming systems. The aim of this paper is to evaluate current evidence for the impact of organic farming systems on soil biological quality and consider the identification of appropriate biological indicators for use by organic farmers and their advisors. Organic farming systems are generally associated with increased biological activity and increased below-ground biodiversity. The main impacts on biological fertility do not result from the systems *per se* but are related to the amount and quality of the soil organic matter pool and disruptions of soil habitat via tillage. Even within the constraints of organic farming practices it is possible for farmers to make changes to management practices which will tend to improve soil biological quality. It is, however, by no means clear that distinct indicators of soil biological quality are needed for organic farming systems. It is important not only to identify the most appropriate indicators but also to ensure that farmers and land managers can understand and relate to them to support on-farm management decisions.

Key words: microbial biomass, organic matter inputs, soil ecosystem, tillage

Introduction

Concerns about environmental degradation and protection, together with increasing consumer awareness of food safety issues, have contributed to the development of a number of 'sustainable' or 'eco' farming approaches in recent decades. Organic farming, first developed in the 1940s, has found a booming market for its products and it is now considered to provide viable livelihoods in many circumstances and a realistic alternative to other more high input–high output approaches to agriculture[1]. Across the world organic farming and processing has well-developed certification systems and, in many countries, the definition and practices of organic agriculture are defined in law (e.g. Regulation 834/2007 of the European Union). There is no single homogeneous and easily recognizable organic farming system. Organic farming systems are underpinned by a set of agreed global principles (Table 1), thereafter crops, livestock and their management on organic farms are regionally diverse and locally adapted.

The health of the soil, recognized by its active role in the linked processes of decomposition and nutrient supply, was proposed as the foundation of agriculture by the pioneers of the organic movement[2,3]. The organic farming movement has developed its principles and recommendations for farm management from an underpinning recognition of the biological, ecological conception of nature and the importance of the relationships and interactions between organisms—plant, animals and within the soil. In contrast, intensification of agricultural production is often marked by increased use of mechanical and manufactured inputs and increased specialization of production; these changes mean

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Table 1. Principles of Organic Agriculture—International Federation of Organic Agriculture Movements, 2005 (http://www.ifoam.org/about_ifoam/principles/index.html).[1]

Principle of health
Organic agriculture should sustain and enhance the health of soil, plant, animal, human and planet as one and indivisible.
Principle of ecology
Organic agriculture should be based on living ecological systems and cycles, work with them, emulate them and help sustain them.
Principle of fairness
Organic agriculture should build on relationships that ensure fairness with regard to the common environment and life opportunities.
Principle of care
Organic agriculture should be managed in a precautionary and responsible manner to protect the health and well-being of current and future generations and the environment.

[1] In the full text, each principle is articulated through a statement followed by an explanation, which is not given here. They are given as ethical principles to inspire action and consequently should be taken as a whole. The principles of organic agriculture serve to inspire the organic movement in its full diversity and guide IFOAM's development of positions, programmes and standards.

that regulation of the agro-ecosystem through biological processes is displaced[4]. Hence in organic farming systems, use of manufactured fertilizers is prohibited (or at least significantly restricted), crops must be grown in rotation or as mixtures. Rotations/mixtures are designed with a strong awareness of their impact on soil structure. The cropping plan is also designed with regard to the fertility building and depleting role of the crops, with a focus on nutrient recycling to reduce the need for external input[5]. Nutrients are dominantly added to the soil as organic (e.g. manures, compost, crop residues and legumes) or slow-release sources (e.g. rock phosphate). Consequently in organic farming systems a greater reliance is placed on chemical and biological processes within the soil to release nutrients in forms available for plant uptake. In this respect, while the processes controlling nutrient availability are the same in soils whether under organic or conventional management, nutrient availability in organically farmed soils is more dependent on soil processes than is the case in conventional agriculture[6]. It is also clear that the role of the soil in weed, disease and pest management may be significant for organic farming systems[7,8]. Soils also play an important role in the regulation of broader environmental quality; for example, taking key roles in the regulation of water flow in watersheds, global emissions of greenhouse gases and degradation of wastes.

There is strong evidence that organic agriculture, particularly in temperate arable systems, is able to deliver positive impacts on biodiversity[9–11], which offset the declines in farmland biodiversity that have been seen in these regions as a result of the intensification of farming systems and consequent homogenization of the landscape[12,13]. A full range of evidence in all climates and farming systems has yet to be collected. The absence of synthetic fertilizers and pesticides, increased diversity of crop types in space and time, together with requirements in organic certification schemes for beneficial management for wildlife in non-cropped areas, are likely to contribute to the increases in biodiversity seen in organic systems[11].

In considering soil biological quality, it is important to take a broad view of 'which organisms count?' and in the first instance consider the whole food web and its interactions. For example it has been shown that the activity of soil fauna is responsible for 30–40% of the N released into plant-available forms in the soil[14]; mineralization is not purely a microbially driven process. Often agricultural systems are associated with simplified soil food webs compared to semi-natural systems; dominantly pastoral systems also have been shown to have qualitatively different ecological interactions below ground than dominantly arable systems[15]. However, agricultural intensification need not necessarily have adverse consequences on below-ground biodiversity[4,16]. In contrast, in a range of grassland systems, it has been shown that increased intensity of management tended to reduce the diversity of soil organisms within most functional groups[17]. This paper will therefore further investigate the evidence for the impact of organic farming systems on soil biological quality and consider the identification of appropriate biological indicators for use by organic farmers and their advisors.

In the following review, where differences between treatments are cited from previously published work, these refer only to significant differences reported in the original work. However, in many cases the published studies reviewed contain evidence of significant increases, significant decreases and no significant differences as a result of farming systems or treatments; the authors of this review have therefore, on many occasions, applied their expert judgment to assess the overall implications of a number of contrasting studies. In these cases, no formal meta-analysis has been carried out and hence no statistical significance is discussed.

Impact of Organic Farming on Soil Biological Quality

Pastoral systems

A large body of work carried out on soil biodiversity at an unimproved grassland site in the uplands of southern Scotland (320 m above sea level) showed that even soils with relatively low above-ground vegetation diversity had

extremely high below-ground biodiversity and were able to process carbon inputs rapidly[18], this resulted in a soil ecosystem that was highly resistant to perturbations, including the application of lime, nitrogen fertilizer and biocides. Almost no work has been done to study the impact of differences between farming systems on soil biological quality in hill pastures. Given that differences between organic and conventional management in hill pasture systems are relatively small, large differences in soil biological quality are not expected. No significant differences were seen in bacterial diversity between improved and unimproved grassland despite differences in grazing intensity, fertilizer use and plant species[19]; there was, however, some indication of an underlying difference in specific population components. Organic management, which is likely to reduce stocking density on unimproved grazing land, may have a negative impact on below-ground ecology in these areas due to reduced nutrient inputs[20,21]. Soil biota was studied along a fertility gradient in permanent pastures in the hills of New Zealand[22] with a range of plant species, stocking rates (6–16 ewe equivalents) and fertilizer applications (to a maximum of 90 kg N and 33 kg P ha^{-1}). Bacteria and nematode populations showed an increase with increasing fertility; the same trends were found in both organic and conventional pastures and the farming systems were not distinguishable[22].

In lowland dairy systems, there are much larger differences between organic and conventional practices. Stocking density is often lower in organic systems. Conventional systems are generally associated with more intensive grassland management. Temperate organic dairy systems are dependent on grass–legume leys, rather than intensively fertilized predominantly rye-grass swards. There is some evidence of reduced numbers and activity of dung beetles where veterinary drugs are used regularly in lowland grassland systems[23]; anecdotal evidence suggests that dung decomposes more slowly where wormers have been used. Impacts on earthworms are less clear; studies have shown both no significant differences in earthworm numbers and species diversity[24,25] and also reduced earthworm numbers[26] when comparing grassland management systems. In a comparison of grassland under conventional (*c.* 5-year grass–clover swards receiving NPK fertilizers) and organic management (>10-year grass–clover swards with a significant proportion of other grass species, slurry applied at one site) on three contrasting soil types (silt, loam and sand), strong interactions were shown between soil and farming system on soil biological quality. Bacterial and mite populations tended to increase under organic management, while fungal and total nematode populations were significantly increased under organic management at all sites[26]. Detailed analysis of nematode populations under conventional and organic management showed that fungal feeders were increased at all sites under organic management, whereas bacterial feeders, predatory and plant feeding species showed strong interactions with site and no clear effect of management[26]. Results from a gradient of grassland sites in The Netherlands[17] showed higher diversity of bacterial and fungal feeding nematodes under organic than intensive grassland management systems—a gradient of practice related to management intensity including increasing livestock density, increasing use of mineral fertilizers and biocides and reducing use of farmyard manure was studied. A study of nematodes across a management intensity gradient in Germany and Switzerland also showed similar trends[27]. The highest nematode diversity was recorded on an organic farm[17]. There was a strong relationship between higher bacterial populations and bacterial feeding nematodes, both increasing with intensity of management. Hyphal feeding nematodes show much lower resilience than bacterial feeders to increasing intensity of farming practices in all grassland systems with lower number of taxa and fewer individuals in general[17]. Arbuscular mycorrhizal fungi have shown greater spore density and infectivity under organic management (grass-clover swards) than at paired conventional sites (with higher rates of fertilizer use and lower proportions of clover[28]). Arbuscular mycorrhizal fungi are likely to be increased as a result of increased plant diversity and decreasing P availability in organic systems[29]; conventional dairy pastures often have very high P availability[30]. Taken together the data collected in grassland systems suggest that decomposition pathways in low-intensity and/or organically managed grassland are likely to be more complex/diverse than under high-intensity conventional grassland, with consequent impacts on the higher trophic levels of the food web. However, there are few studies of the impact of organic management on predatory meso- and macrofauna in lowland grassland systems.

Rainfed arable cropping systems

Most studies comparing the effects of organic, integrated and conventional systems have been carried out in temperate rainfed arable systems. In these systems, there are large differences between organic and conventional management. All systems are permitted to use lime to maintain an optimum pH. However, there are marked differences in the use of mineral fertilizer, herbicides and pesticides. Organic livestock-based ley–arable systems use grass-clover leys and manures to maintain soil fertility; stockless organic farms use N fixing green manure crops at the heart of their rotations[5]. Tillage intensity varies in both conventional and organic systems, though due to the prohibition of herbicides, zero-till systems are less common in organic systems.

Paired farm studies in New Zealand have shown greater microbial biomass in organic than conventional systems[31,32]. However, where organic management was compared with conventional systems using reduced tillage, no differences were found in the size of the microbial biomass[33]. Soil type (sand compared with clay) was shown to have a larger effect on the size of the microbial biomass than farming system in a comparison of 13 paired sites[34].

Under field conditions in a long-term trial comparing a conventional system, an organic system based around animal production using manures, and a stockless organic system using N fixing cover crops[35], there were only very small differences between the size of the microbial biomass but significant differences between activity of the populations[36]. Larger microbial biomass populations and higher respiration rates have been measured in the grass–clover ley phase of organic rotations[37]. Increased microbial biomass in forage compared with arable rotations has also been found in conventional and integrated systems[38]. There was no equivalent distinction between organic arable and forage rotation in the same trial; it was proposed that the higher returns of organic matter, as a result of the inclusion of ley and green manure crops in the organic arable rotation, offset the impact of increased tillage[38]. In a long-term comparison of farming systems under the same crop rotation in Switzerland, soil microbial biomass size and activity were shown to be more sensitive than the total soil organic carbon pool to differences in the quantity and quality of applied animal manure[39]. Detailed observations of microbial population size, composition and dynamics and populations of other below-ground fauna made in a long-term multidisciplinary study under irrigation in a Mediterranean climate[40–42] confirm the findings from temperate climates that the main factors leading to the increase in microbial populations and activity that are observed under organic management are the quantity and quality of the carbon inputs.

There is some indication that organically managed soils have a larger population of viable but non-culturable microorganisms[43]. There is also some indication of increased diversity of bacterial populations under organic management[44]; however, a large number of factors varied between the sites studied. Soil properties that regulate microbial activity may also regulate microbial community composition[45]; management practices that modify soil pH and cycling of dissolved organic matter are most important in modifying microbial community structure and activity. Higher functional diversity coupled with higher microbial carbon efficiency have been measured under organic management[46]. At the same site genotyping approaches have been used to show that the structural diversity of bacterial communities was influenced more by the application of animal manures than by conventional or organic management *per se*[47]. This work was extended using lipid profiling to study microbial phenotypes to confirm that application of farmyard manure had the strongest influence on microbial community structure[48]; in addition an influence of conventional versus organic management could be distinguished, whereas no direct impact of the immediately previous crop could be identified. Interaction between tillage and organic matter inputs within the constraints set by climate and soil texture rather than management system *per se* dominantly control the size and activity of the soil microbial biomass in arable systems.

Ergosterol (as an indicator of fungal biomass) was compared in soils from an organic, a conventional arable and conventional livestock farm[49]. The conventional livestock farm had greater ergosterol contents than the conventional arable farm. The biodynamic system that had a mixed cropping rotation, and intermediate inputs of organic matter had intermediate ergosterol contents. Spatial heterogeneity in ergosterol also increased with increasing pool size. However, in other cases few (and no consistent) differences in fungal biomass appear between organic and conventional systems[43]; indeed, the variation in fungal abundance within farming systems has been shown to be as great (and often greater) than differences between farming systems[50]. Higher arbuscular mycorrhizal colonization has been shown in organic than conventional paired cropping systems[51–53]. Using a paired farm approach it was shown that arbuscular mycorrhizal fungi in organic farms had a higher infectivity to roots than conventional systems (compared at the same inoculum levels)[54], infectivity also increased with time since conversion to organic management; the largest difference was seen on an inherently low P status soil. At the Rodale Research Institute in Pennsylvania, three farming systems (conventional, organic based around animal production using manures and stockless organic system using N fixing cover crops) showed similar levels of arbuscular mycorrhizal fungi[55]; all plots also had very high levels of available P. A higher diversity of arbuscular mycorrhizal fungal spores under organic management regimes has also been shown[51,56]. Summarized evidence from 13 available studies showed greater root colonization, larger numbers of spores and greater diversity of arbuscular mycorrhizal fungi in organically managed soils[28]. However, poor performance of arbuscular mycorrhizal fungi was also identified in some organic systems[28]; the causes could not be identified because of differences in the details of management practices used in organic systems and contrasting land management at the sites before conversion.

Protozoans and nematodes are primary consumers of the soil microbial biomass and may be more sensitive indicators of the microbial dynamics than the measurements of the microbial biomass itself[57,58]. No differences were shown in protozoan populations between organic and conventional farming systems in Austria[23]. The nematode community structure has been shown to vary with fertilizer and crop protection systems[59]; different components of nematode biomass responded differently to different management practices. Overall nematode abundance has been shown to be higher under organic management than in comparable conventional systems[23,60]. However, a larger effect of soil type (sand compared with clay) compared to farming system was found in The Netherlands on the size of the total nematode population in a comparison of 13 paired sites[34]. It has been observed that organically managed arable land in a crop rotation maintained nematode species diversity and species type at a level more similar to low intensity grass than comparable conventional arable systems[26].

Long-term system studies have found fundamental differences in soil food web structure between conventional and less intensive farming systems (The Netherlands[61], USA[62] and Sweden[63]). Microbes, protozoa and nematodes have been shown to contribute more to the total amount of N mineralized in a lower-input system, while in the conventional system mites and enchytraeids made a larger contribution to mineralization[64]. Contribution to mineralization is a function of both species abundance and turnover[64]. It has been suggested that, as for grassland systems discussed above, under conventional arable cultivation, the bacterial community dominates the microbial component while, in less intensive systems, the fungal community is the dominant microbial component. Such differences influence nutrient cycling and have implications for the efficient use of nutrient inputs and leaching potential[65,66]. Long-term system studies in The Netherlands, USA and Sweden[61–63] have also found that most soil faunal groups were more diverse or unchanged in less intensive farming systems (organic and integrated) than in conventional systems. In addition, no difference in collembolan population size or species abundance was evident between conventional systems using reduced tillage and organic farming systems[33]. Many collembolan taxa have been shown to be ubiquitous in arable farming systems[67], where the most important source of variation was local differences between management practices. However, in general, taxa responded differently to farming systems; it has been suggested that collembolan species showing an increase in organic farming systems are those that prefer increased humidity and hence higher weed populations[67]. Significantly higher carabid populations have also been reported in organic management regimes[68]. A meta-analysis of all the data collected on comparisons of carabids in organic and conventional systems in southern Germany and Switzerland showed that on average there were 34% more species found in organically managed winter wheat[69]; carabid species also responded to management systems differently, with some species showing increases and some decreases in organic systems. Identification of key species traits and requirements is needed if optimum management practices for any particular species are to be developed, e.g., *Carabus auratus* often shows increased populations in organic farming systems. However, this effect is not found on very sandy soils, and shows a strongly negative response to mechanical weeding in spring due to its long larval stage[69]. Earthworms are generally higher in organic than conventional systems[31,68]. Within organic rotations earthworm numbers were found to be highest in the second year of grass–clover ley, the population declined through the tillage phase of the rotation with increased time after the ley phase[70]. Increases in earthworm population have been strongly linked to farming systems with reduced cultivation[71].

Beneficial effects of organic farming on the abundance and species richness of arable weeds are often reported, e.g., Roschewitz et al.[72]. This clearly has benefits for plant species diversity and can therefore impact on above ground insect diversity[73]. The presence of weeds can act as an important bridge for arbuscular mycorrhizal fungi in non-mycorrhizal crops[74]. It is likely that the presence of increased weed populations may have broader impacts on the soil ecosystems. Selected biological indicators of soil quality have also been associated with potential weed-suppressive activity in soil. In reduced tillage systems, the proportion of water-stable soil aggregates was the greatest in soils with the highest organic matter and was found to be related to higher enzyme and weed-suppressive activity[75]. Interactions between crops, weed and soil biological quality are complex and not much studied.

Lowland rice (paddy) systems

Little work has been carried out in paddy systems to compare biological soil quality between organic and conventionally managed systems. However, differences have been found in the ground arthropod community structure and insect pest regulatory mechanisms[76]. No consistent structural differences were found in the abundance of plant eating and predatory arthropods in comparisons of organic and conventional rice paddies[77]. The same study also demonstrated that soils under organic management had lower bulk densities. Improved soil physical quality (including ease of cultivation) has been shown in organic rice systems and this has been linked to the larger returns of organic matter through rice straw and animal manure typically associated with organic management practices[78]. Given the very different soil processes operating under the reducing environment in rice paddies, more work is needed to establish whether these changes in soil physical quality and organic matter management have any measurable impact on soil biological quality.

Overall impacts on soil biological quality

Given our limited ability to apply robust taxonomic classification systems to below-ground groups, it is probably not surprising that a range of positive and negative effects on below-ground ecology are observed as a result of the application of contrasting management systems. The evidence collected until 1992 on the impacts of organic management on soil biodiversity showed uncertain results: 'It is increasingly evident that generalisations like—conventional farming destroys life in the soil or Eco-farming stimulates soil life—are only partially supported by the data'[23]. More recent reviews have largely shown positive impacts of organic farming systems on soil biological quality. A larger number of studies showing positive impacts of organic farming systems on below-ground species than studies showing no difference or negative impacts were reported in a 2005 review[10]. As part of a meta-analysis considering all aspects of biodiversity in organic farming systems in 2005, it was shown that despite the considerable heterogeneity amongst studies, soil organisms were generally more abundant in organic farming

systems[8]. Effects on bacterial biomass and activity were unclear, whereas positive impacts on earthworms, collembolan, mites and fungal populations were confirmed. For groups that can be resolved to the species level, e.g., collembola and carabids, differential effects of systems are found for different species.

Interactions between tillage and management of the carbon cycle (both the amount and quality of inputs) dominantly control soil biological quality within the constraints set by the particular climate/soil conditions at any site. Tillage intensity seems to have the most significant effect in reducing soil biological quality. Impacts of cropping management (particularly the amount and quality of organic matter returned to the soil) can moderate the impact of even quite severe tillage operations and seem to increase the resilience of below-ground ecosystems. Increased use of ley–arable rotations and green manures in organic farming systems tends to increase the amounts and diversity of organic matter inputs compared to conventional arable rotations. Consequently, both organic and reduced tillage systems have positive effects on soil biological quality, though significant variations are found within any defined farm management system. Much smaller differences in soil biological quality are seen in grassland systems, where differences in management between organic and conventional management are also often smaller. For grassland systems, balancing grazing intensity in space and time, together with the considered use of drainage, aeration, fertilizers, lime and organic inputs, all affect the impact of agricultural management on soil biological quality.

Using indicators of soil biological quality in organic farming systems

Consideration of the current evidence on the impact of organic farming systems on soil biological quality indicates that while organic farming practices generally have a positive impact on soil biological quality, differences between practices within farming systems have as great (or often greater) impact on soil biological activity than the farming system *per se*. Consequently, even within the constraints of organic farming practices, it is possible for farmers to make changes that will improve soil biological quality. It is, however, by no means clear that distinct indicators of soil biological quality will be needed for organic farming. Most of the measurements of soil biological quality and soil ecology discussed above have used the same methods for both organic and conventional systems. Although a greater reliance is placed on chemical and biological processes within the soil in organic farming systems to release nutrients in forms available for plant uptake, the processes controlling nutrient availability are the same in soils whether under organic or conventional management[5]. There is much that can and should be learned from the literature on soil quality indicators for conventional farming systems[79,80] in the search for appropriate indicators of biological quality for application within organic farming systems.

There is currently no reliable method to predict the impact of management on the soil microbial biomass and its whole range of activity due to the complex interaction of site and management factors (both directly and indirectly) and the ability of the soil microbial biomass itself to alter the soil habitat in response to management changes[81]. Changes in biological methods, including (but not exclusively) those based on molecular methods, now offer new ways of examining the size, diversity and activities of the groups within the soil population. This is an area of intense research activity and scientific excitement and provides major opportunities for developing new indicators of changes in soil relevant to specific activities and functions. However, in the context of monitoring soils and detecting trends or problems, caution is required in interpreting the large amount of data that can now be collected[82–84]. Factors and management practices that increase resilience are also likely to vary for different below-ground organisms and may include management in both cropped and no-cropped habitats—for insect species the maintenance of a source of organisms able to re-invade may be critical (i.e., size, proximity and connectivity with an unaffected community). In some circumstances, management practices can also provide a reservoir population, e.g., using intercrops or tree saplings inoculated with appropriate mycorrhizal fungi. Where inoculation with mycorrhizal fungi and pseudomonads had been used to improve crop yield under organic management then a modification of the soil microbial structural diversity can be detected using denaturing gradient gel electrophoresis[85]. Such analytical approaches have not yet been developed to allow definition of target states or ideal ranges so that their measurement could guide management, e.g., distinction between sites that would benefit from inoculation from those with appropriate existing microbial diversity. Even where the use of biological inoculation is so far advanced, such as for rhizobia, the understanding of the soil and environmental factors necessary to characterize the specific requirements or limitations in the soil for establishing *Rhizobium* populations to ensure optimal nitrogen fixation following inoculation of legumes remains incomplete[86]. In this case a simple chemical measurement, pH, was found to be the best indicator of an aspect of soil biological quality, i.e., the survival and effectiveness of rhizobial strains[87]. A quest for indicators of soil biological quality should not immediately reject chemical and physical measurements.

In a search for appropriate indicators of soil biological quality it is appropriate to note the cautionary comment made by the late Ted Elliott[88]:

> The ideal bioindicator of soil health would be simply measured, work equally well in all environments and reliably reveal what problems existed where. For the reasons outlined ..., we are more likely to develop bioindicators for which information is laboriously obtained, that are specific to a given ecosystem or environmental problem and only tell us that there is a problem

> and not show us what the problem is. Even with this gloomy forecast, it is unquestionable that we will continue to seek ways by which we can determine the health of ecosystems, or their components, such as soil.

In the literature on soil quality, almost entirely written by soil scientists rather than soil users, there is a strong tendency to develop lists of measurements that can be made on soils and then interpret them as indicators of soil quality, e.g., Karlen et al.[89]. In part, this tendency to make measurements reflects the training and mode of working of reductionist scientists. Consequently, a common approach, contained in much of the literature summarized in the consideration of the impact of organic farming systems on soil quality above, is to measure as many things as possible in contrasting systems and then use statistical approaches to identify those showing significant differences, so that these can be proposed as indicators, e.g., Xua et al.[90] This can lead to the identification of a good set of descriptor measurements which can be used to distinguish between systems and/or high and yield variants in a system[91]. Some groups favor the development of an index that normalizes measured soil quality indicator data and generates a numeric value that can be used to compare various management practices or to assess management-induced changes over time[92]. However, there has been much less work showing the added value of using these approaches predictively and/or to guide management. In practice, these approaches will often lead to a sensible analysis of an issue or problem, given that soil scientists should have a good understanding of the relationships between soil properties and functions. However, we suggest that the stakeholders or land managers most concerned in a given situation should be engaged at an early stage of the process to define the outcomes or functions they require. The soil scientists should then, and only then, work alongside them to develop a set of measurements or observations that will provide information on these functions. In practice, the two approaches may often lead to the same set of measurements—but not always.

Where we are seeking to develop indicators that will guide changes in farming practice, then farmers must also be able to manipulate the indicator beneficially and such manipulation must be cost effective. Consequently, it is important not just to identify the most appropriate indices but also to ensure that these can be quantified with the necessary precision and that farmers and land managers can understand and relate to them[93]. This requires an awareness of the constraints of a farming system, whether legislative, as for many organic farming systems, or physical, economic, etc. For example, the constraints of the organic principles to on-farm practice may mean that some indicators developed for conventional farming systems therefore have little/limited use in organic farming system since the actions which they are designed to trigger are not permitted in organic farming management. For example, while development of a rapid and reliable detection method for evaluating soil inoculum levels in naturally infested soils might trigger the selection of resistant or partly resistant cultivars (e.g., for *Plasmodiophora brassicae*[94]) and hence be a useful screening method in organic as well as conventional systems, a screening method developed for use within the growing season to trigger a fungicide application would be of limited use to organic farmers.

Often authors of reviews on soil biological fertility argue that maintenance and enhancement of soil biological fertility is generally of benefit within agricultural systems, e.g., Doran and Smith[95], Beauchamp and Hume[96] and Clapperton et al.[97]. However their guidance as to monitoring and management of soil biological fertility at a farming system level is given only in very general way. For example: 'Ideally agroecosystems should be managed to maintain the structural integrity of the [soil] habitat, increase SOM and optimise the C : N ratios in soil organic matter using cover crops and/or crop sequence to synchronise nutrient release and plant uptake'.[97] But a farmer might well ask how many cover crops and which ones, where the right balance (economic as well as ecological) is between minimizing tillage and optimizing weed control ... and many more pertinent questions. Interactions between practices, rather than the impact of any single practice, are often the focus of farm management decisions. In the development of indicators of soil quality, closer links to management practices are needed, so that indicators can support improved quality of soil management.

Conclusions

The legislative requirements placed on organic farming systems mean that many of the practices which are likely to maintain or enhance soil biological fertility are at the heart of this approach to farming. It is a requirement of organic farming systems that they recycle nutrients within the farming system, so that total returns of organic materials to the soil are often higher under organic management. In addition, organic farming systems develop diverse cropping patterns in space and time, hence increasing the diversity of residue quality input to the soil. Consequently, many organic farming systems have increased biological activity and increased below-ground biodiversity compared with conventional farming in the same region. However, within organic farming systems, weed management is largely achieved through tillage and perhaps the key remaining question for organic arable farming systems with regard to the enhancement of soil biological fertility is to what extent can minimum tillage approaches can be adopted?

There is no evidence that new distinct indicators are needed to measure biological soil quality in organic farming systems. For all farming systems, the key is to identify indicators that are suitably responsive to changes in practice and can be readily interpreted by the farmer. More work is needed, however, to test existing indicator frameworks (e.g., Idowu et al.[79]) to guide management within organic farming systems, rather than simply to compare organic and conventional management.

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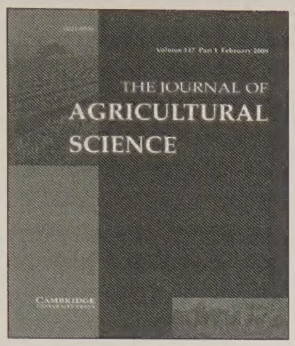

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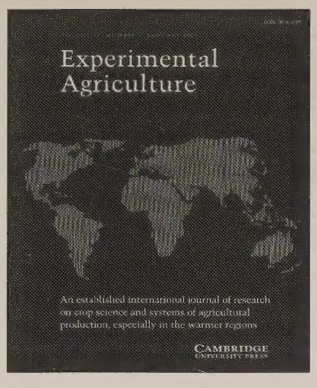
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Preliminary Report

Effects of organic nitrogen fortifiers on some growth parameters of green amaranths (*Amaranthus caudatus* L.)
O.O. AdeOluwa, G.O. Adeoye, and S.A. Yusuff 245

Research Papers

Consumer demand for local produce at extended season farmers' markets: guiding farmer marketing strategies
David S. Conner, Adam D. Montri, Dru N. Montri, and Michael W. Hamm 251

Protocol for indicator scoring in the soil management assessment framework (SMAF)
B.J. Wienhold, D.L. Karlen, S.S. Andrews, and D.E. Stott 260

Purchasing foods produced on organic, small and local farms: A mixed method analysis of New England consumers
L. Berlin, W. Lockeretz, and R. Bell 267

The profitability of organic soybean production
W.D. McBride and Catherine Greene 276

Nutritional and quality characteristics expressed in 31 perennial wheat breeding lines
Kevin M. Murphy, Lori A. Hoagland, Philip G. Reeves, Byung-Kee Baik, and Stephen S. Jones 285

Browsing for conservation: Springtime forage value of midstory shrubs of degraded oak savannas in southern Wisconsin
Janet Hedtcke, Joshua Posner, Martha Rosemeyer, and Ken Albrecht 293

Review Articles

Soilless cultivation for high-quality vegetables with biogas manure in China: Feasibility and benefit analysis
Wen Ke Liu, Qi-Chang Yang, and Lianfeng Du 300

Biological indicators of soil quality in organic farming systems
E.A. Stockdale and C.A. Watson 308

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